Fiber Optics

Installation — Maintenance

MatriX Engineering

Student Notes

Chapter 1

Communications Basics

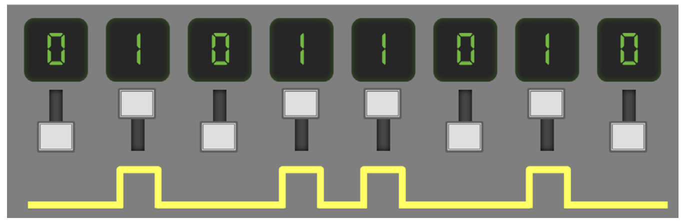
By the end of this chapter, you will be able to:

- Name the three parts of an optical fiber
- List the core and cladding sizes of typical optical fibers
- Describe the units of measurement typically used in fiber optics
- List some of the advantages and benefits of fiber optics
- Explain the difference between standards and codes

Digital Communications

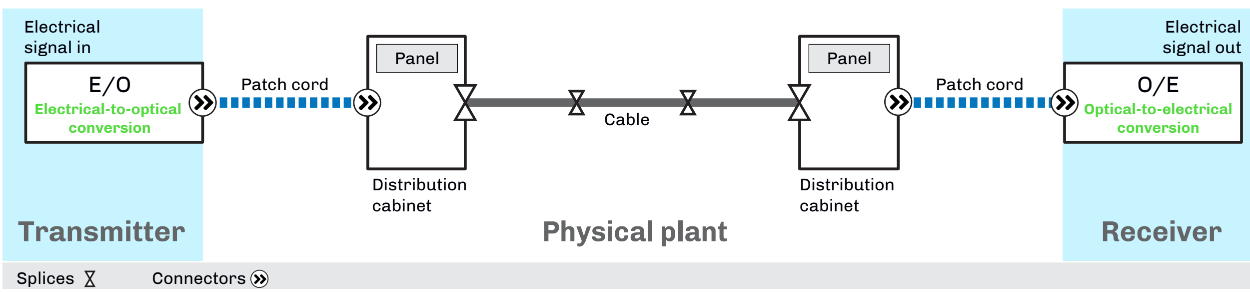
The Binary System

- Binary information can be transmitted serially (one after another) by turning a single light on and off over time to form "words"
- Fiber optic systems turn a transmitter on ("high") and off ("low") to send pulses of light down the fiber



- Digital information is represented as a series of ones and zeros
    - Electronic devices use tiny switches to represent the ones and zeros

Using Light as a Communications Method



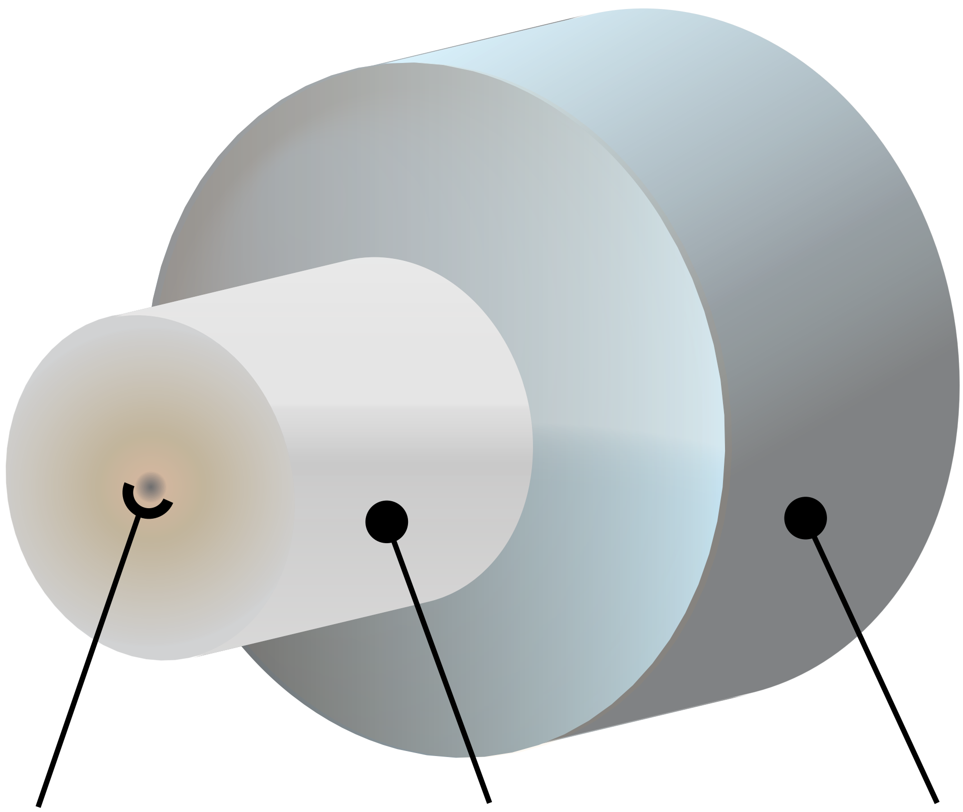
- An electronic signal is converted through an optical light source to light pulses
- The light pulses propagate down the fiber through the core
- A receiver converts the lights pulses back to an electronic signal

An optical fiber transmission system consists of three parts:

1. **Transmitter.**
    - Most often uses a laser diode as a light source.
2. **Physical plant.**
    - The physical infrastructure that makes up an entire fiber optic network
        - Fiber — Can be multimode or single-mode.
        - Cable — Protects the fibers. Designed for specific applications.
        - Connectors — Allow for temporary connections at equipment and panels.
        - Splices — Permanent joining of two fibers.
        - Panels — Allow for patching and splicing of fibers.
        - Cabinets — House panels and splices.
3. **Receiver.**
    - Receivers will have a dynamic range of power that they can accept. Dynamic range is the difference between the minimum and maximum input power, while the minimum input power is considered the receiver's sensitivity.

What is an Optical Fiber?

Most fibers used in fiber optic communications systems have a silica glass core surrounded by a silica glass cladding. This is covered by an acrylate plastic coating, which protects the glass during handling and cabling processes, and a thin outer coating to provide color identification. The characteristics of the fibers vary depending upon the materials used and the process of manufacturing.



The Core

Where light
is transmitted

- Glass or plastic
- Higher index of refraction (n) than the cladding
- Light travels in the core
- 9 µm, 50 µm, 62.5 µm sizes

The Cladding

Surrounds the core
Contains and reflects light

- Glass or plastic
- Lower index of refraction
- Light reflects off core/cladding boundary
- Outside diameter is 125 µm

The Coating

Protects and
identifies the fiber

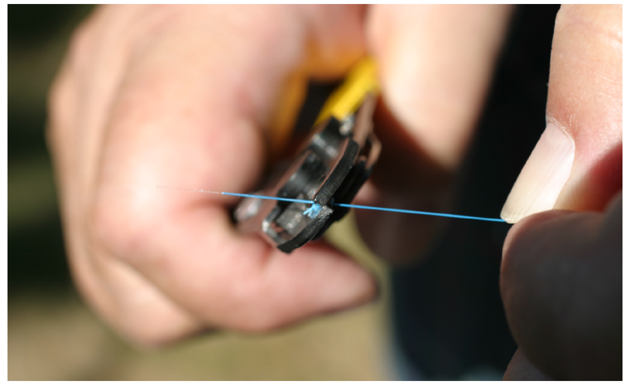
- 200- or 250-µm coating for protection
- Strippable – can be removed
- Outer surface of coating often colored for identification

The core and cladding are fused together.
They cannot be separated.

The coating can be
stripped off.

Fiber Coatings

Most optical fiber receives an acrylate coating to a diameter of 250 microns, but different types and diameters of coating can be applied depending on the application of the fiber. The coating aids in fiber handling and provides protection against bending, damage to the glass surface, environmental effects, and mechanical stress. Stripping the coating off will remove this protective layer. Coatings are applied as part of the fiber manufacturing process and are usually UV cured. Colors and additional buffer materials may be applied during the cabling process.



Optical Fiber Color Coding

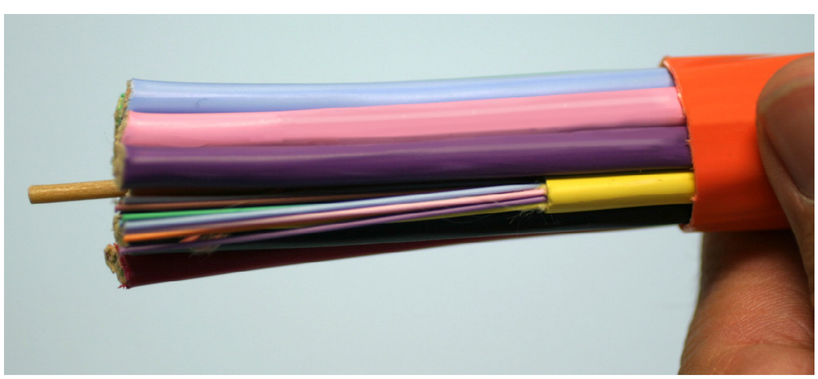
In every optical cable, it is necessary to quickly and accurately identify individual fibers. The TIA-598 standard specifies a 12-color code to be used on fiber coatings as well as buffer tubes, or sub-units containing individual fibers.

Fibers 13-24 are the same color as fibers 1-12, with the exclusion of the black fiber. In TIA-598, fiber 20 is black with a white tracer.

With loose tube cables, fiber groups are separated with color-coded buffer tubes or threads that repeat the same color order. The first buffer tube or thread would be colored blue and would contain all twelve colors from fibers 1-12. The second buffer tube containing fibers 13-24 would be orange. Each fiber in the sequence would be either individually color-coded, or have one colored fiber and the rest would be identified by their position in relationship to the reference fiber.

The color coding sequence varies from region to region. Please consult your local standards and recommendations for the proper sequence in your area.

Fiber #	Coating Color
1	Blue
2	Orange
3	Green
4	Brown
5	Slate
6	White
7	Red
8	Black
9	Yellow
10	Violet
11	Rose
12	Aqua



Basic Units of Measure in Fiber Optics

As a universal technology, fiber optics uses the metric system as the standard form of measurement. Several of the more common terms are:

Meter (m) 39.37 inches, or just slightly larger than a yard (36 inches).

Kilometer (km) 1,000 meters (3,281 feet), or approximately 0.62 miles.

Micrometer (µm) One millionth of a meter. There are 25 microns to one thousandth of an inch (0.001). In fiber optics, it is referred to as “micron” and is used in the dimensional measurement of fibers.

Nanometer (nm) One billionth of a meter. Used to express the wavelength (λ) of transmitted light.

Metric Conversion

Kilometers x 0.62 = Miles
Miles x 1.61 = Kilometers

Meters x 3.281 = Feet
Feet x 0.3048 = Meters

Centimeters x 0.03281 = Feet
Feet x 30.48 = Centimeters

Meters x 39.37 = Inches
Inches x 0.0254 = Meters

Centimeters x 0.3937 = Inches
Inches x 2.54 = Centimeters

Millimeters x 0.03937 = Inches
Inches x 25.4 = Millimeters

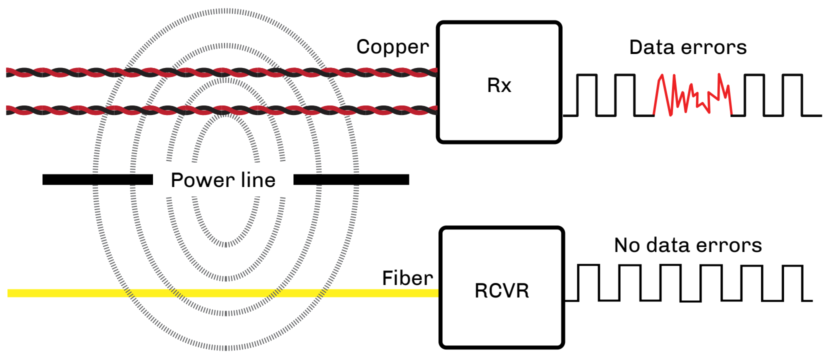
International System of Units (SI) Common Prefixes

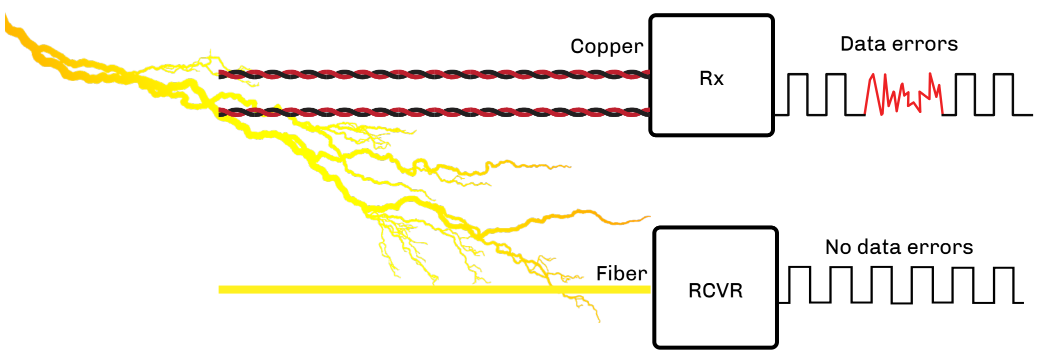
Quantity	Power	Prefixes	Symbols
1,000,000,000,000,000	10^{15}	Peta	P
1,000,000,000,000	10^{12}	Tera	T
1,000,000,000	10^{9}	Giga	G
1,000,000	10^{6}	Mega	M
1,000	10^{3}	Kilo	k
100	10^{2}	Hecto	H
10	10^{1}	Deca	dk
0.1	10^{-1}	deci	d
0.01	10^{-2}	centi	c
0.001	10^{-3}	milli	m
0.000001	10^{-6}	micro	µ
0.000000001	10^{-9}	nano	n
0.000000000001	10^{-12}	pico	p
0.000000000000001	10^{-15}	femto	f

Advantages of Fiber Optics

1. **EMI immunity.**

   Unlike systems using metallic conductors, which require shielding from electromagnetic radiation, optical fibers are dielectric and are not affected by electromagnetic interference (EMI) or radio frequency interference (RFI).





2. **Low loss (attenuation).**

   Single-mode fibers have losses as low as 0.17 dB/km at 1550 nm. Multimode losses are as low as 0.6 dB/km at 1300 nm. This creates opportunities for longer distances without costly repeaters.

3. **High bandwidth.**

   While optical fiber theoretically has a bandwidth of more than 500 Tb/s (10^{12}), in practice it is operated at much lower speeds. However, transmission at multiple Terabits per second is not uncommon and fiber has been tested in the lab to support more 70 Tb/s. This is far faster than any metallic-based transmission method.

Advantages of Fiber Optics

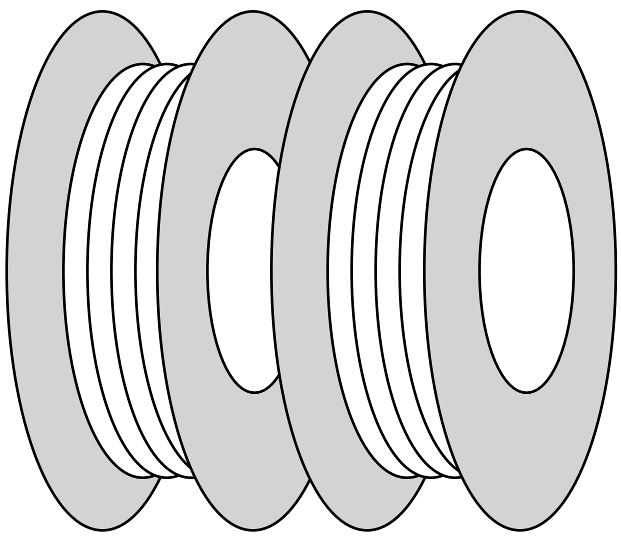
(Continued)

4. **Small size.**

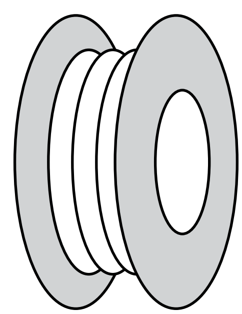
   A 1/2” (24) fiber-optic cable operating at 40 Gb/s can handle 143,360 times the amount of voice channels as a 3” diameter (900) twisted pair cable. Smaller size provides better duct utilization.

5. **Lightweight.**

   The same 1/2” fiber-optic cable weighs approximately 176 pounds per kilometer. The 3” twisted pair cable weighs in at 16,000 pounds. This allows for longer pulls during installation.



Copper cable
900 pair
21,600 VFC (T1C)
3” cable O.D.
16,000 lbs per kilometer



Fiber cable
24 fiber (6 Tx/6 Rx)
(12 spare and standby)
3,096,576,000 VFC @ OC-768
0.559” cable O.D.
176 lbs per kilometer

7. **Transmission security.**

   Because fiber is dielectric, it does not radiate electromagnetic pulses, radiation, or other energy that can be detected. This makes the optical cable difficult to locate. In addition, methods to tap into fiber create a substantial system signal loss.

8. **Non=sparking for hazardous environments.**

   Fiber is glass and provides a safe transmission medium. It does not carry electrical current, and is non-sparking for applications in dangerous or explosive environments.

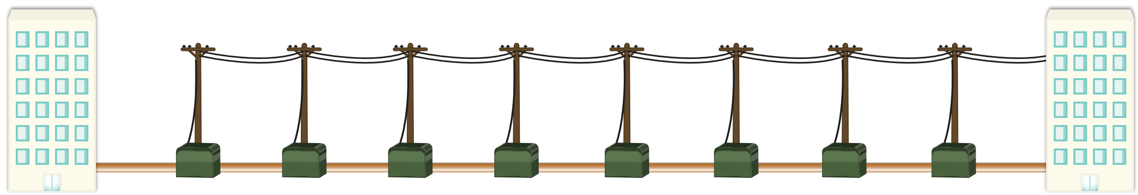
9. **Wide temperature range.**

   Standard fibers and cables are manufactured to meet temperatures from −40°F to +160°F (−40°C to +70°C).

Additional Benefits of Fiber Optics

1. **Fewer repeaters.**

   Compared to metallic systems, fewer repeaters are required.



Repeaters in a copper system

Repeaters in a fiber system

2. **Stable performance.**

   Fiber optics is affected less by moisture and thermal conditions than copper. This means less corrosion and degradation. Therefore, less maintenance is required for the physical plant.

3. **Costs.**

   Costs are decreasing due to increased competition, larger manufacturing volumes, higher yields with better quality, and standardization of common products.

4. **Upgradeability.**

   Because of its extreme bandwidth capabilities, very few installed fibers are operating anywhere near their maximum capacity. Therefore — through techniques such as wavelength division multiplexing and increased bit rates — they offer an upgrade path that does not require replacement of the physical plant.

5. **Material availability.**

   Glass optical fibers are manufactured from silica, the material that comprises sand. Unlike copper, silica is in abundance throughout the world and is readily available.

Standards Committees

Fiber-optic technology has always embraced standardization.

In the early R&D and implementation years in the 1970s, the TIA-455 and IEC 60793 standards established the first fiber optic test procedures (FOTPs). The universal acceptance of these FOTPs provided a strong foundation for testing and measurement.

In the early 1980s, the first transmission system standards were published. Organizations such as ANSI, ITU, and IEC released standards for fiber distributed data interface (FDDI), SONET/SDH, and Telcordia released the first General Requirements. Fiber optic variations for Ethernet and Token Ring were also written. As communications systems and applications expanded, so were the standards: IEEE 802.6 for metropolitan area networks, ANSI's Fibre Channel, and ITU standards for dense wavelength division multiplexing (DWDM) and fiber to the home(FTTH).

In the 1990s, system design and installation standards such as TIA-568, -569, -606, -607, and ITU-T G.983 FTTH were developed. After 2000, FTTH standards included IEEE 802.3 EPON and active Ethernet, ITU G.984 G-PON, and SCTE 174. The ITU and IEEE also approved standards for 10 Gb/s transmission in 2009 and 2010, and for 40 Gb/s and 100 Gb/s transmission in 2010 and 2014.

- Test and measurement standards – 1970s to present.
  - TIA-455 fiber optic test procedures (FOTPs), 526, 626, IEC 60793.
- Transmission standards – 1980s to present.
  - DWDM; Ethernet; FTTx/PON; FDDI; OTN; SONET/SDH.
- Installation and design standards– 1990s to present.
  - IEC 11801, 60825; NEC; NESC; TIA-526, 568, 569, 590, 626, 758.
- Standards versus codes.
  - Standards are industry accepted guidelines.
    - TIA-568.
    - IEC 60793.
  - Code compliance is required by law and can vary by country.
    - NEC and CEC.
    - NESC.

Standards Committees
(Continued)

International Bodies

IEC — The International Electrotechnical Commission establishes standards for all electrical, electronic, and related technologies. Comprised of National Electrotechnical Committees.

ISO – The International Organization for Standardization establishes industrial, technical, material, and testing standards..

Both IEC and ISO develop standards that are consensus-based, represent industry needs, and are not sponsored by companies or organizations. The two organizations often work together through joint committees.

ITU — The International Telecommunication Union is a specialized agency of the UN that coordinates the radio spectrum, communication satellites, and technical standards for next-generation networks.

Industry Organizations

TIA — The Telecommunications Industry Association is accredited by ANSI to develop voluntary, consensus-based standards for the telecommunications industry.

Private Organizations

ANSI — The American National Standards Institute is a private, non-profit organization that accredits standards developers, and coordinates documents from other standardizing bodies for use in the United States. ANSI is the only American representative of the ISO and IEC.

Telcordia — A subsidiary of Ericsson that operates as a for-profit research laboratory, Telcordia's primary importance is as a historic developer of requirements for hardware components in optical communication systems.

Professional Organizations

IEEE — Within the Institute of Electrical and Electronics Engineers, the IEEE Standards Association is responsible for the development, publication and revision of IEEE standards.

SCTE – The Society of Cable Telecommunications Engineers is a non-profit professional association. Its global arm is the International Society of Broadband Engineers. SCTE-ISBE is accredited by ANSI and recognized by the ITU.

U.S. Government Agencies

DOD — The Department of Defense

NIST — The National Institute of Standards and Technology, a non-regulatory agency of the U.S. Commerce Department, is largely focused on basic metrology and testing.

Chapter 1 Review

1. What parts of an optical fiber are not strippable?

2. Which is longer: a nanometer or a kilometer?

3. Does the failure to follow a code have legal ramifications?

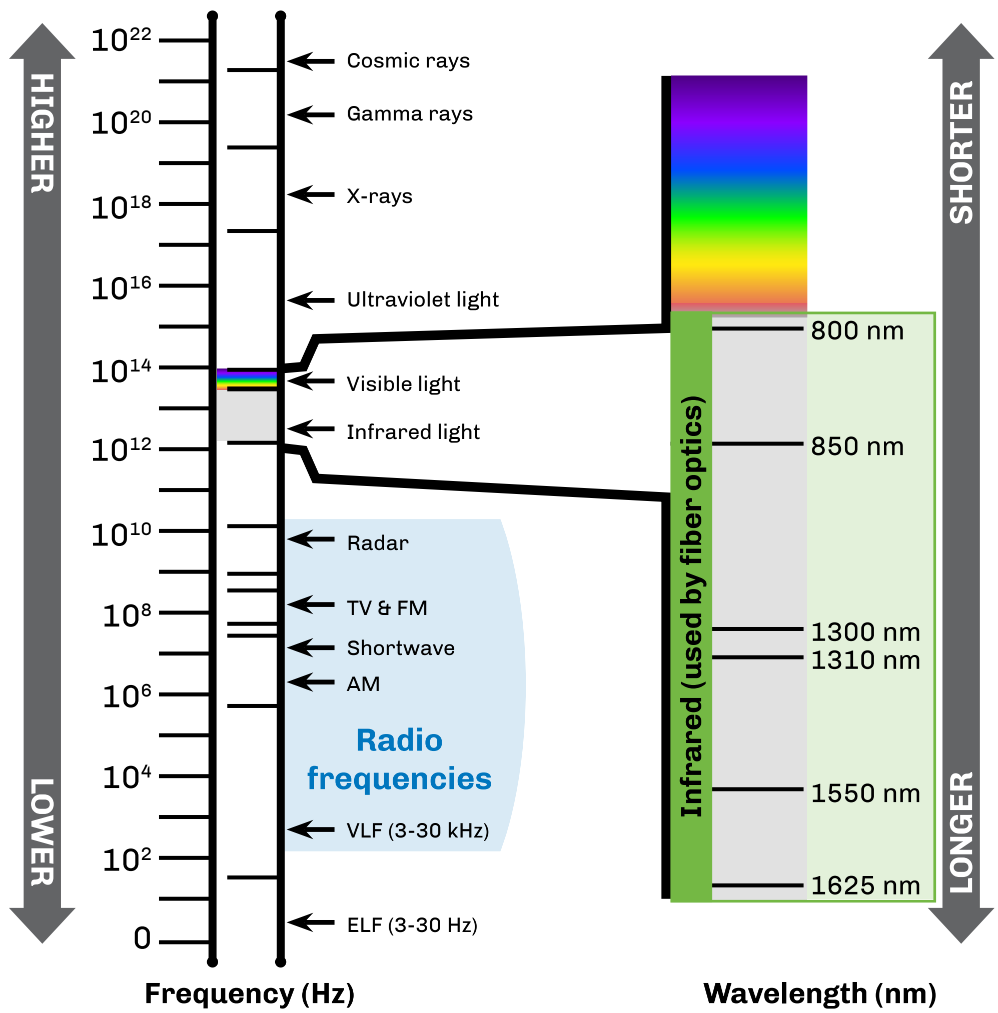
Chapter 2

Fiber Optic Transmission Theory

By the end of this chapter, you will be able to:

- Describe the basic components of an optical transmission system
- Discuss the operating principles of optical transmission
- Describe intrinsic and extrinsic factors impacting optical system performance

The Electromagnetic Spectrum



Light operates in a higher frequency and shorter wavelength than radar, TV, and radio.

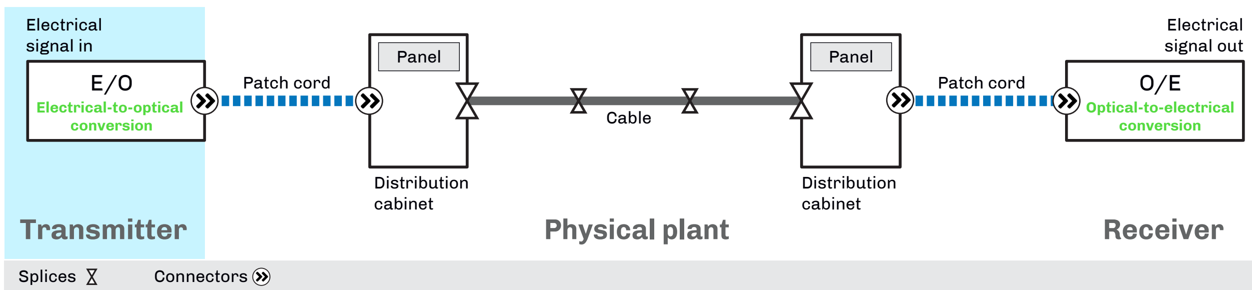
Standard Transmission Wavelengths

Fiber optics typically uses the transmission wavelengths between 770 nm and 1675 nm. These infrared regions, which are invisible to the human eye, are where optical signal loss is lowest.

- Multimode fiber typically transmits at 850 and 1300 nm.
- Single-mode fiber can transmit between 1260 nm and 1650 nm, but typically uses 1310 nm and 1550 nm.

Fiber Optic Transmitters

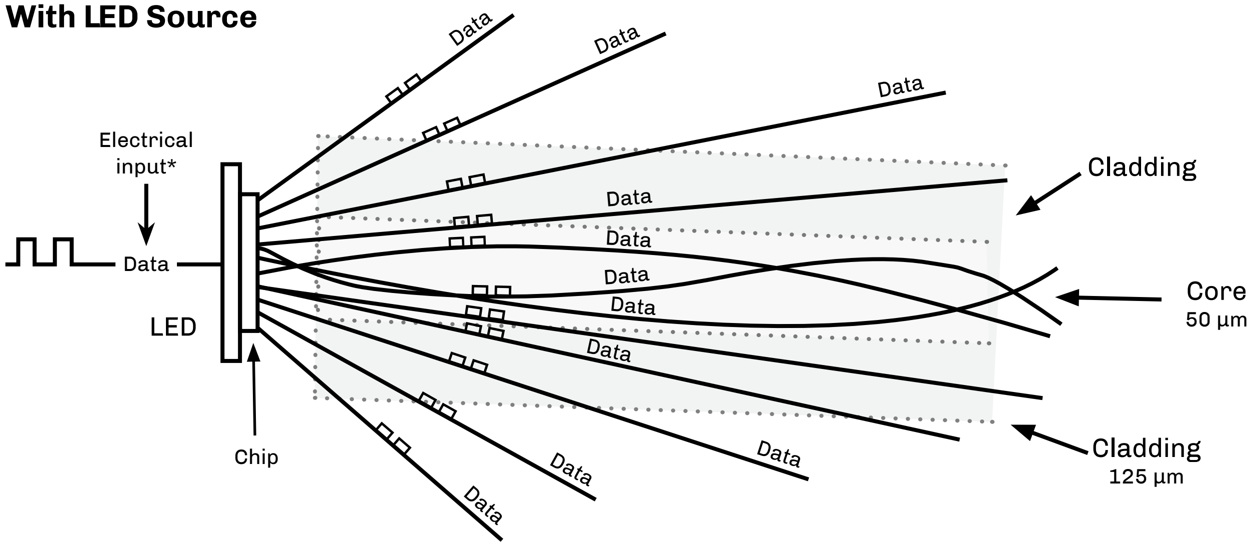
A fiber optic transmitter consists of a modulator of some type and either a light-emitting diode (LED) or laser light source. The transmitter modulates the light source to convert the electrical signal (Ethernet, SONET, RF, etc.) to an optical signal. Using a simple binary on/off keyed digital signal (as an example), it converts this information into optical light pulses by turning the light source on (bright) and off (dim) in the correct sequence, and then launches the resulting signal into an optical fiber.



- Can use a light-emitting diode (LED) or a laser diode
- Converts electrical signals into optical signals
- Launches the optical signals into the fiber

Multimode Systems

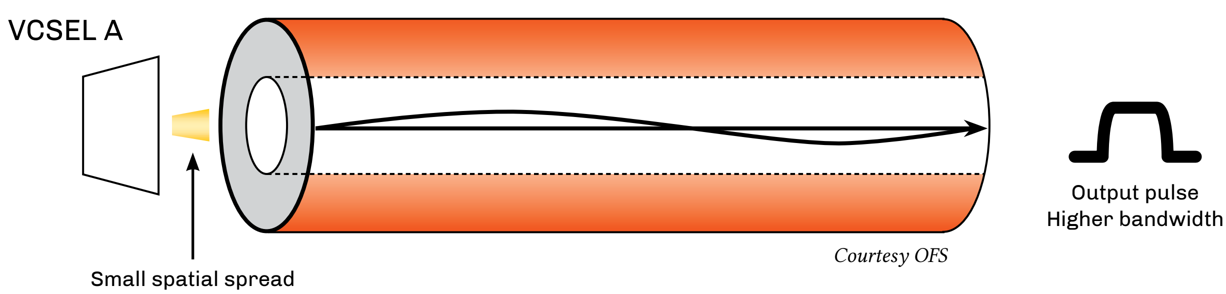
With LED Source



In a multimode fiber, light energy propagates as hundreds of modes, each carrying the same data.

Historically, light-emitting diodes (LEDs) are limited to maximum modulation rates of slightly less than 1 Gb/s. At greater speeds, a laser must be used.

With VCSEL Source



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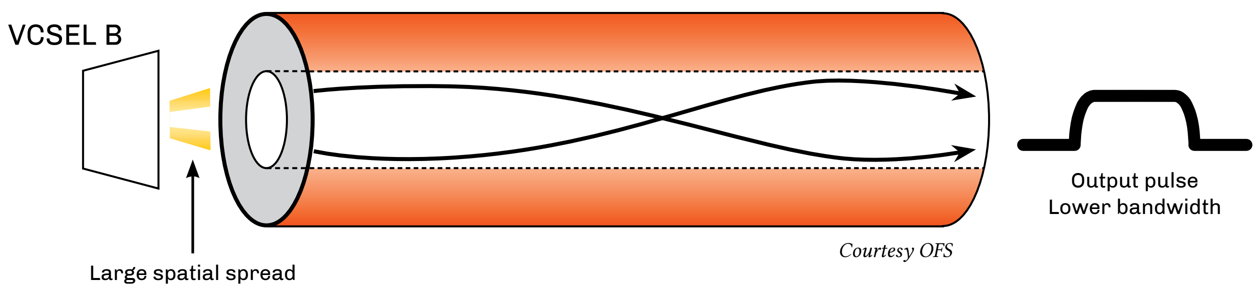

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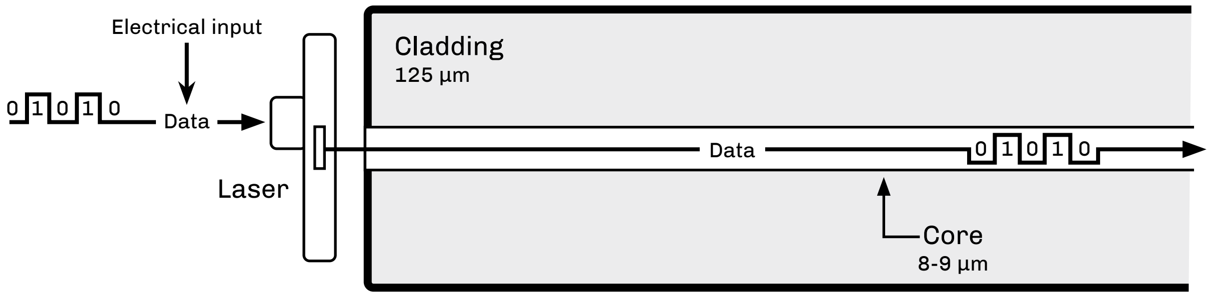
Vertical-cavity surface-emittng lasers (VCSELs) in transmission and test equipment can launch more (or less) optical energy into the outer core, affecting bandwidth and signal loss.

Single-mode Systems

With Laser Source



Single-mode fibers have a core of approximately 8-9 microns and a cladding diameter of 125 microns.

Early point-to-point (P2P) single-mode systems operated at 1310 nm and 1550 nm. Long-haul P2P systems migrated to the 1550-nm window (since optical amplifiers function within that spectrum), or operate at multiple wavelengths closely spaced at or near 1550 nm. Many other wavelengths are used in coarse wavelength division multiplexing (CWDM) and fiber-to-the-premises (FTTx) systems.

- Fabry-Perot (FP) laser
  - Relatively broad spectrum (3-5 nm)
- Distributed feedback (DFB) laser
  - Narrow spectrum (<0.1 nm)
  - Sensitive to reflections

The dBm Scale

dBm

Used to express the optical power in a fiber optic system

An absolute logarithmic measurement of optical power relative to 1 mW of optical power

dB

Used to express optical loss, gain, and reflection

dB values are obtained by calculating the difference between input power and output power

"dBm" is an abbreviation for "dBmW", which is one decibel (dB) relative to one milliwatt (mW) of power. Using a logarithmic scale is a convenient way to express very large and very small levels with small numbers.

dBm +/− dB = dBm

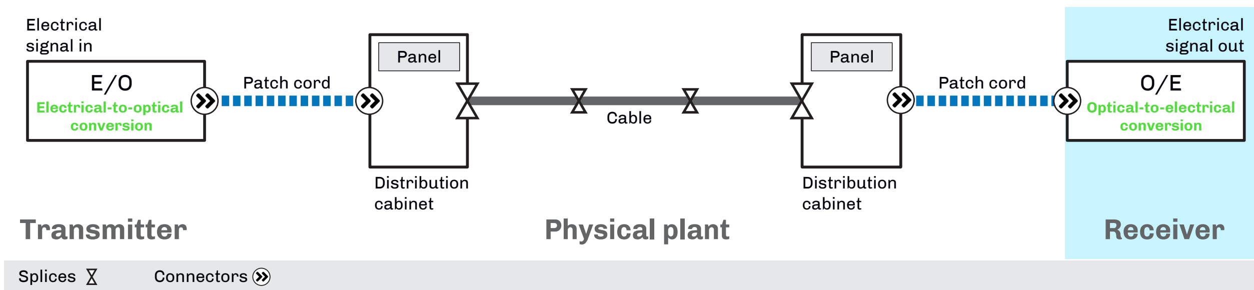
dBm +/− dBm = dB

- Any dBm value less than zero, i.e. −3 dBm, is less than 1 mW of power, while any dBm value greater than zero is more than 1 mW of power.
- A 10 dB increase is a gain equal to 10X the original power. A 10 dB decrease is a gain equal to 1/10th (10%) the original power.
- An increase of 3 dB is double the power. An decrease of 3 dB is half the power

dBm	Milliwatts	Watts
30	1000	1
20	100	0.1
10	10	0.01
0	1	0.001
−3	0.50	(500 µW)
−4	0.40	(400 µW)
−6	0.25	(250 µW)
−7	0.20	(200 µW)
−10	0.10	(100 µW)
−20	0.01	(10 µW)
−23	0.005	(5 µW)
−30	0.001	(1 µW)
−33	0.0005	(500 nW)
−60	0.000001	(1 nW)

Fiber Optic Receivers

Optical detectors, also known as photo diodes and photo detectors, perform the reverse function of the transmitter: they convert incoming optical signals (light pulses) into electrical signals that are then processed with conventional circuitry within the optical receiver. The converted signal is amplified and sent to a data decoder or demodulator that converts it into voice, video, and/or data.



- The photodiode or photodetector in the receiver converts the optical signal back into an electrical signal.
- Receivers will have a "sensitivity" range of powers that they can accept.

Loss and Attenuation

The loss of optical signal in a fiber is measured in dB, or decibels. The term “decibel” derives from the prefix “deci” from the Latin term “decimus” meaning “tenth,” and “Bell” after Alexander Graham Bell. This is why in its abbreviated form, the “d” is always lowercase and the “B” is always capitalized.

dB is both a logarithmic function and a relative value that is used to denote the decrease of optical power between two points (attenuation), or the percentage of the signal reflected by an optical component such as a connector (reflection).

Attenuation, in dB

$$-10 \log \frac{\text{Power out}}{\text{Power in}}$$

Light Loss Measurement

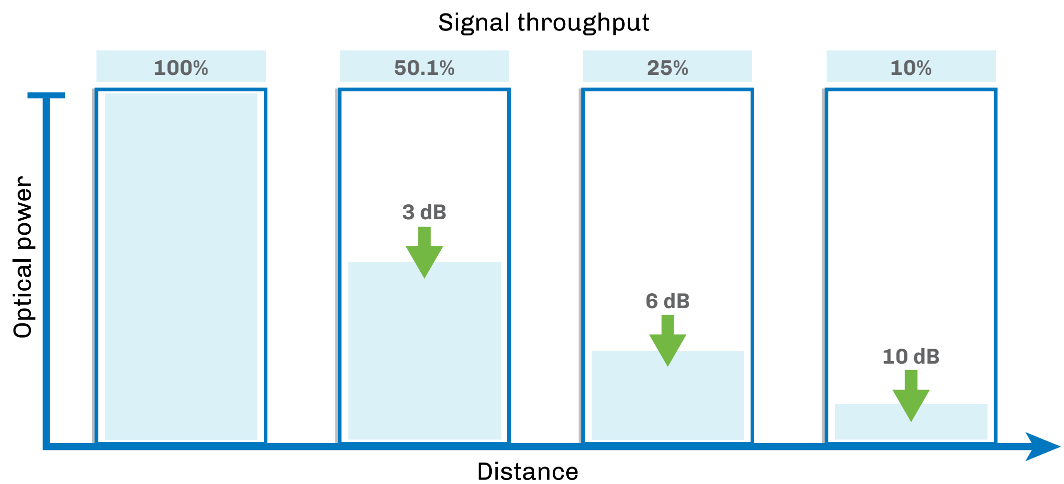
- Represents the ratio of signal gain or loss.
- Loss, gain, and reflectance are expressed as “dB”.
- Attenuation in optical fiber is expressed in decibels per kilometer, or dB/km, at a given wavelength.
- Sample values:
  - Single-mode fiber attenuation: 0.35 dB/km @ 1310 nm
  - Multimode fiber attenuation: 3.0 dB/km @ 850 nm
  - Connector loss: 0.5 dB

Signal Loss Chart (dB)

dB	Throughput %	Loss %
0.00	**100.0**	**0.0**
0.01	99.8	0.2
0.02	99.5	0.5
0.05	98.9	1.1
0.1	97.7	2.3
0.15	96.6	3.4
0.2	95.5	4.5
0.25	94.4	5.6
0.3	93.3	6.7
0.4	91.2	8.8
0.5	89.1	10.9
0.6	87.1	12.9
0.7	85.1	14.9
0.8	83.2	16.8
0.9	81.3	18.7
1.0	79.4	20.6
1.1	77.6	22.4
1.2	75.9	24.1
1.3	74.1	25.9
1.4	72.4	27.6
1.5	70.8	29.2

dB	Throughput %	Loss %
1.6	69.2	30.8
1.7	67.6	32.4
1.8	66.1	33.9
1.9	64.6	35.4
2.0	63.1	36.9
3.0	**50.1**	**49.9**
4.0	39.8	60.2
5.0	31.6	68.4
6.0	25.1	74.9
7.0	20.0	80.0
8.0	15.8	84.2
9.0	12.6	87.4
10.0	**10.0**	**90.0**
15.0	3.2	96.8
20.0	1.0	99.0
25.0	0.3	99.7
30.0	0.1	99.9
35.0	0.03	99.97
40.0	0.01	99.99
45.0	0.003	99.997
50.0	0.001	99.999

Attenuation



Attenuation is the loss of light or power in an optical signal. As the signal is transmitted along the medium (the fiber), a percentage of the signal is lost. The amount of loss that occurs varies based on the type of fiber and the operating wavelength. The longer the wavelength, the lower the attenuation.

Attenuation in optical systems can be identified as intrinsic or extrinsic. Intrinsic attenuation is inherent or "built into" the fiber material and the cabling and manufacturing processes, and cannot be changed. Extrinsic attenuation results from outside factors such as bends in the fiber. Components such as connectors, splices, and splitters add their own attenuation, both intrinsic and extrinsic. Most components in a fiber network have maximum attenuation (loss) values recommended by the standards, nominal loss values for planning and design, and then "real world" or actual loss values, confirmed by testing.

Optical Power Loss

Power Can be Lost Anywhere in the Network

Fiber	Splices	Connectors
Intrinsic • Absorption • Scattering **Extrinsic** • Macrobends • Microbends **Other** • Attenuators • Splitters/couplers	**Intrinsic** • Core and cladding ovality • Fiber defects • Core/clad eccentricity • Core diameter mismatch • Profile mismatch **Extrinsic** • Misalignment of cores • Distortion of core during fusing	**Intrinsic** • Core and cladding ovality • Fiber defects • Core/clad eccentricity • Core diameter mismatch • Profile mismatch **Extrinsic** • Polish quality • Undercut • End separation • Center radius/core mismatch • Fiber/ferrule diameter tolerance

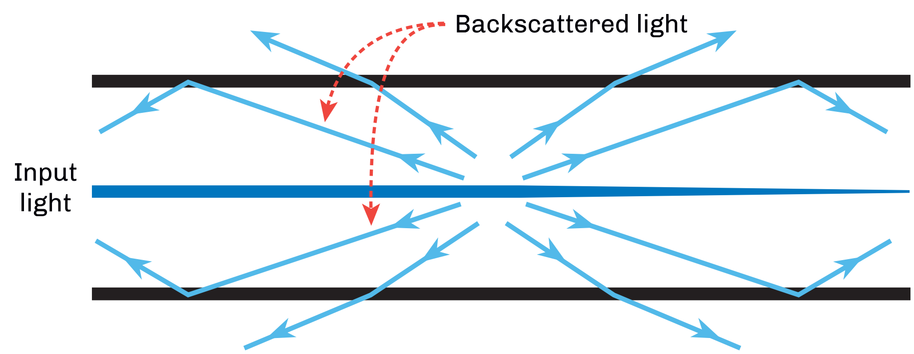
Intrinsic Attenuation

Rayleigh Scattering

This effect is caused by undissolved particles, boundary roughness, refractive index fluctuations, and other intrinsic molecular or optical impurities introduced into the fiber during the manufacturing process.

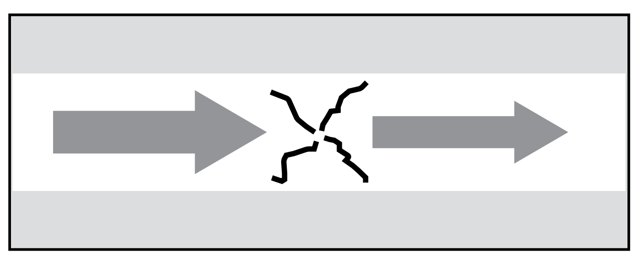
- Caused by the interaction of light with the molecular structure of the fiber
- Causes light to be scattered in all directions
- Small amount of light is captured by the core and reflected back to the source
  - Referred to as “backscatter”
  - OTDRs work partially on this principle
- Decreases as wavelength increases

Scattered light is reflected in all directions. A small portion of this light is captured by the fiber core and returned back to the optical source. This backscattered light is used by optical time-domain reflectometers (OTDRs) to perform optical measurements. The OTDR measures this light and displays it as attenuation.



Absorption

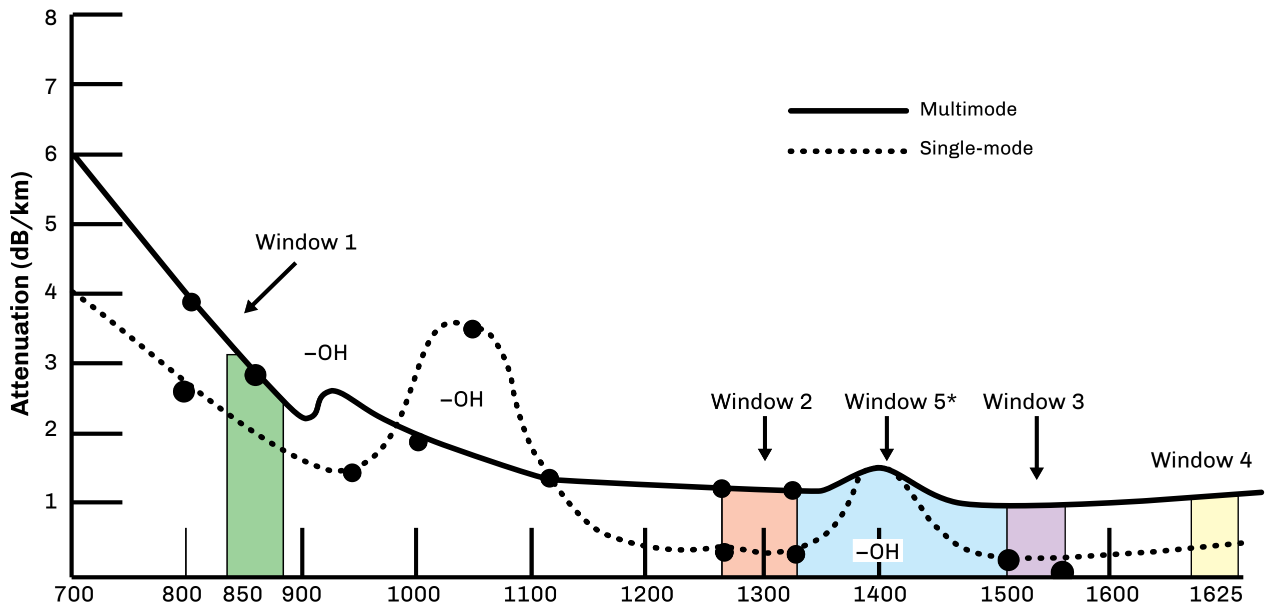
Absorption creates loss in the fiber by absorbing light energy and converting it to heat. The amount of absorption also varies with wavelength and depends upon the composition of the glass.



- Caused by the interaction of the light with the molecular structure of the fiber.
- Creates loss by absorbing light energy and converting it to heat.
- A fiber may exhibit isolated regions of spectrum (wavelengths) with very high absorption (and attenuation) due to OH- (water) content in the fiber.
- Absorption becomes a more significant mechanism at wavelengths above 1550 nm.

Lightwave Transmission

Intrinsic Attenuation and Wavelength



*Hydroxyl ion (–OH) absorption causes loss

OH absorption by hydroxyl ions causes attenuation at specific wavelengths in optical fibers.
Until recently, the industry used wavelengths outside these locations.

Wavelength (nm) – Technically the distance between peaks of a given color of light, each wavelength corresponds to a unique frequency of electromagnetic energy. Wavelengths used in optical communications are in the infrared spectrum, so are invisible to humans. Early point-to-point systems operated at 1310 nm and later 1550 nm to take advantage of low loss. Long-haul systems use multiple wavelengths near 1550 nm to take advantage of optical amplification. FTTx systems may use two wavelengths on the same fiber, e.g., 1310/1490 nm, operating in different directions.

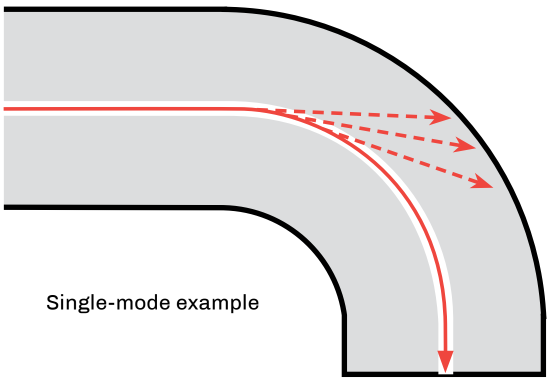
Windows – Wavelength regions of relatively low loss on the fiber were initially referred to as windows (of operation). The first window was near 850 nm, the second window was near 1300 nm, and 50-µm fibers operated as multimode fibers at those wavelengths. A 9-µm core fiber would operate as a single-mode fiber in the second window, but we refer to single-mode operation here as 1310 nm (as distinct from 1300 nm). Single-mode fiber also operated in the third window, near 1550 nm.

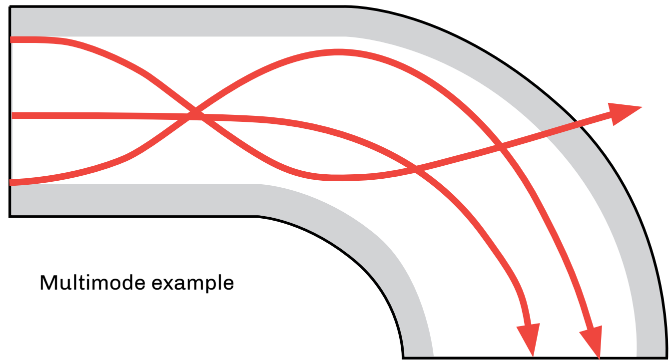
Bands – The single-mode spectrum is further divided up into bands.

Band		Wavelength	Description
O	Original	1260-1360 nm	Relatively low loss fiber region with low-cost transmitters available.
E	Extended	1360-1460 nm	Band centered on the high-loss 1383-nm water peak. Usually avoided (the “excluded” band) unless low water peak fiber is installed.
S	Short	1460-1530 nm	Low loss region not suited to amplifier operation.
C	Conventional	1530-1565 nm	Lowest loss region where C-band amplifiers can operate.
L	Long	1565-1625 nm	Lowest loss region where L-band amplifiers can operate.
U	Ultra long	1625-1675 nm	Used for monitoring and testing. Most susceptible to fiber bending loss.

Extrinsic Attenuation

Macrobending Losses

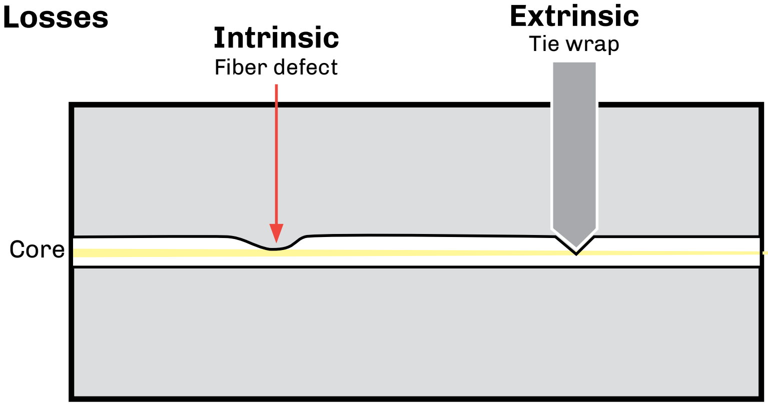




Macrobending occurs when transmission loss increases because the fiber radius has decreased to the point that light rays begin to pass through the cladding boundary. These fiber rays reflect at a different angle, creating a circumstance where higher-order modes are refracted into the cladding and escape. As the radius decreases, attenuation increases. Excessive bending of a fiber will ultimately cause it to break.

The increase in attenuation due to bending will depend on the fiber type, design, and operating wavelength. Higher wavelengths are more susceptible to bending losses than lower wavelengths. Single-mode bend-insensitive (BI) fibers can be used in patchcords, pigtails, in-building installations, and drop cables where bending and handling are more likely. They can be specified for FTTx, RFoG and other systems designed to operate in the region above 1550 nm. Bend-insensitive multimode fibers (BI-MMF) are also widely available for specific applications.

Microbending Losses

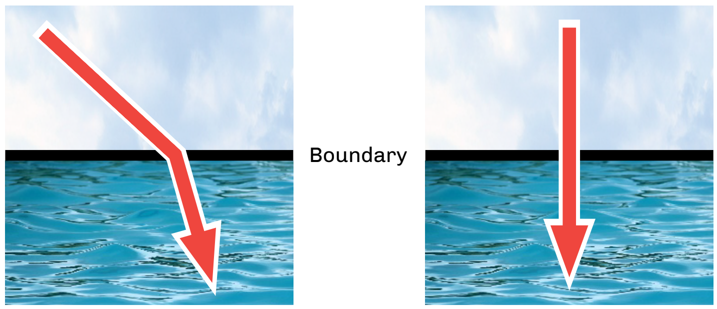


Microbending losses are caused by deviations of the core/cladding boundary. Stresses on an installed cable from tie wraps, clamps, or sharp rocks can also cause microbends.

Note: Single-mode fibers are particularly sensitive to macrobending and microbending losses. If the fiber exhibits higher loss at 1550 nm than at 1310 nm, it identifies bending or some type of stress as the cause.

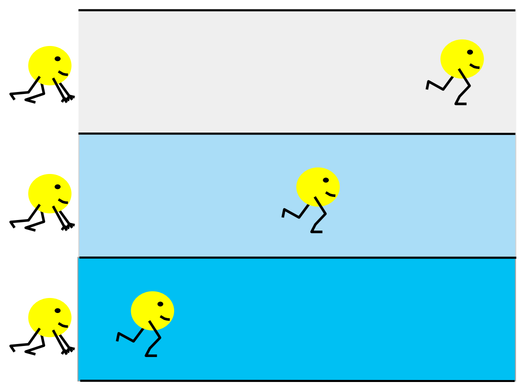
Refraction

Refraction is the bending of a beam of light as it passes through the boundary between two materials that have two different densities. Light is only refracted when it enters into the new material at an angle. If the light travelled straight down, it would continue straight down and not refract.



Speed of Light

Light travels at different speeds through different materials. The lower the density of the material – its index of refraction (n) — the faster the light will travel through it. Light moves the fastest in a vacuum, and slower through materials with higher densities.



Index of Refraction (IOR)

IOR or "refractive index" (n) is a ratio of the speed of light in a vacuum (c) to the speed of light through a transmission medium (v). $n = c / v$

The speed of light through a vacuum is 186,282 miles per second (299,792 kilometers per second). Its speed through an optical fiber varies based on the fiber type, manufacturer, and wavelength. For example, light travels through a particular optical glass at 126,642 miles per second. Based on the formula, the IOR through that glass would 1.471.

Speed of light	Miles per second	Kilometers per second
In a vacuum	186,282	299,792
Through the optical fiber	÷ 126,642	÷ 203,802
Index of refraction	1.471	1.471

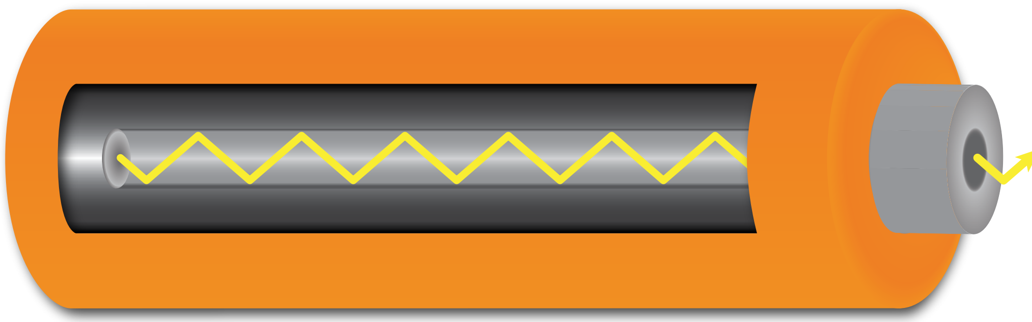
In another optical glass, the light travels at 126,900 miles per second, so the IOR for this glass would be 1.468. The faster the measured light is travelling through the optical fiber, the lower the IOR of the material.

Optical fibers have different glass for the core and cladding, each with a different IOR. It is this difference that keeps the light confined within the core.

Total Internal Reflection

In 1841, Daniel Colladon, a professor at the University of Geneva, first demonstrated light guiding by focusing sunlight into a thin stream of water flowing through a hole in a water tank. When the light hit the forward edge of the water flow, he observed that the light rays were trapped in the water stream. This is now known as total internal reflection.

Light propagates through optical fibers by the principle of total internal reflection. It occurs when a core with a higher index of refraction is bounded by a cladding with a lower refractive index. This interface point between the two materials acts like a mirror to keep the light reflecting in the core.



Total internal reflection
Multimode example

Total internal reflection only occurs when the light signal propagates at an angle lower than the critical angle.

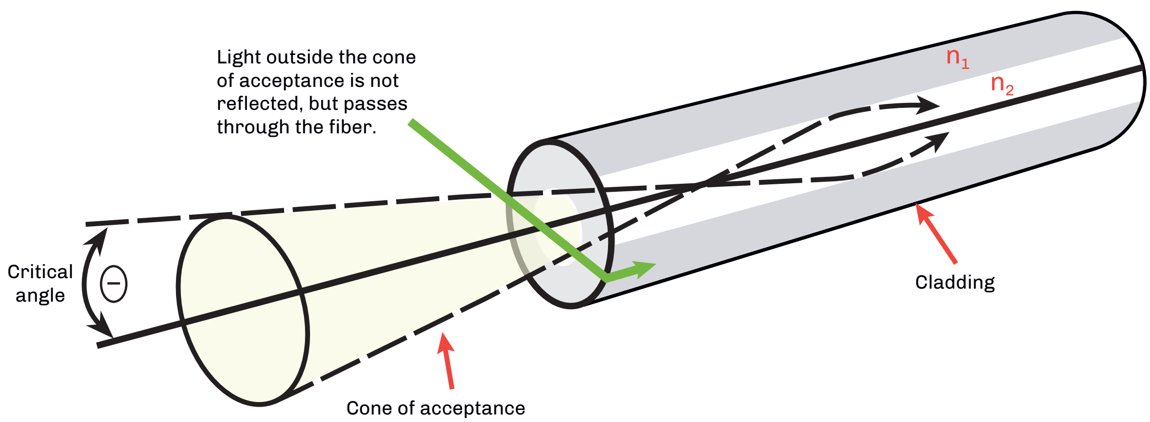
Numerical Aperture

Light Gathering Ability

The maximum angle from the fiber axis at which light can propagate and still be captured by the core is called the critical angle. If this angle is rotated 360° around the fiber axis, it describes the cone of acceptance. Light propagating inside this zone will be captured by the fiber core, while light propagating outside this zone will not.

The sine of the critical angle is called the numerical aperture of the fiber. Numerical aperture does not vary greatly between fibers of the same type. The NA is intrinsic and cannot be influenced by the user. It is of primary interest to device (transmitter, splitter, receiver) manufacturers and can be largely disregarded by the user or operator.

Note that a small portion of light propagating outside the cone of acceptance may be captured in the cladding or become a very high order (loosely bound) mode within the core. This light energy may propagate for a short distance but will self-extinct. These can cause some inaccuracies in power and loss measurements. Techniques are available to obtain accurate measurements by filtering or stripping these "leaky" modes.



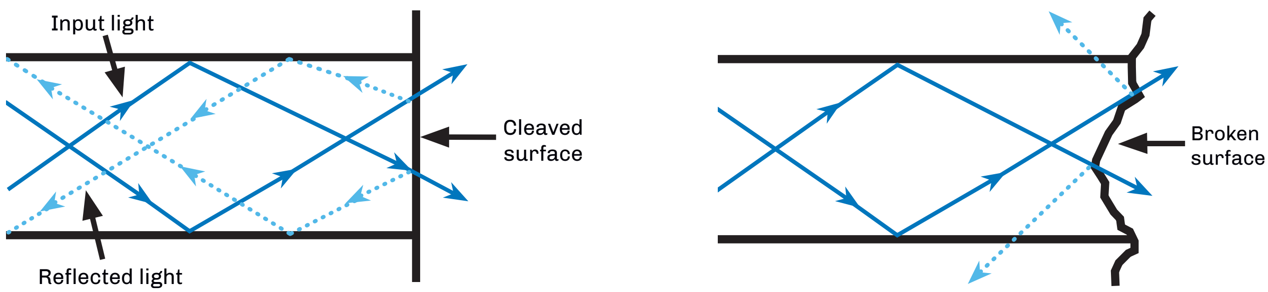
Optical Reflection

Fresnel Reflection

When light energy travels from a medium of one index of refraction (IOR) to a medium with a different IOR, the transfer is not 100% efficient. Some of the light energy will be reflected back into the original medium. This effect is called Fresnel (*fruh-nell*) reflection. The magnitude of the reflection is proportional to the difference between the two IORs. The direction of the reflection captured by the fiber core and returned to the transmitter is dependent on the geometry of the boundary between the two media.

Reflectance from a flat perpendicular fiber end exposed to air can be as high as about 3% (−14 dB) of the original signal sent back up the fiber core. Reflectance from a shattered endface may not be captured by the core. This will measure on an OTDR, for example, as a non-reflective break. Angled physical contact (APC) connectors are specifically designed to vector this reflected energy so that it is not trapped by the core, improving connector performance by about 20 dB.

Excessive energy reflected back to the transmitter can cause transmission problems, particularly for distributed feedback (DFB) lasers. Light undergoing multiple reflections and returning to the receiver after delay can be perceived as noise (multipath interference, MPIF).



Reflectance is the magnitude of light returned back down the core, as a fraction of the forward signal, expressed in dB. It represents the local reflectance value at the component (connector, splitter, splice, etc.) location. Reflectance will always be a negative number.

Optical return loss (ORL) is the term for the total optical power received back to a transmitter placed at some point in a fiber span. It is measured at the transmitter and includes local and distant reflections and backscatter as well as the attenuation between the source of the reflection (or scattering). Because it is expressed as a loss, it is expressed in dB as a positive value.

ORL can be a little confusing at first but the calculation can be better understood by an example. A reflective connector with a −40 dB reflectance is located 1 meter from a transmitter. Its contribution to ORL as measured at the transmitter is essentially −40 dB, as 1 meter of fiber has essentially zero loss. If the same connector is placed 15 km away from the transmitter and the fiber loss between the transmitter and the connector is 10 dB, then the reflectance of the connector is still −40 dB. But the ORL contribution of the connector is −10 dB (loss forward of Tx signal) plus −40 dB (reflectance of connector) plus −10 dB (loss on return trip). So the distant connector only contributes −60 dB of reflected energy or −60 dB of return loss. In this case, the fiber backscatter contribution along the 15-km route would also have to be added to the ORL.

Both reflectance and ORL are expressed in dB. That reflectance is a negative value and ORL is a positive value may be confusing. Consider that with any value, positive or negative, the further it is from zero means less reflectance or ORL.

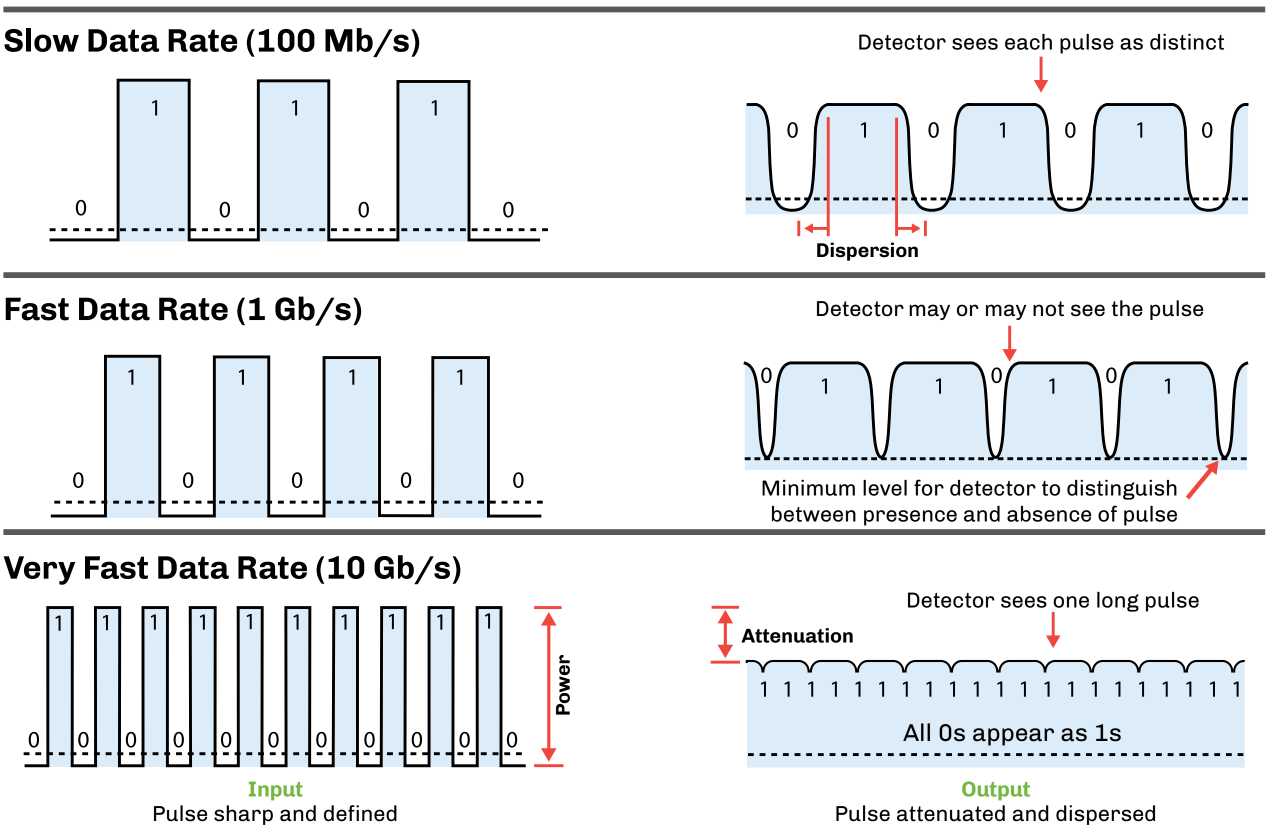
Optical Dispersion

Dispersion is a phenomenon in which some portion of the optical energy in a modulated pulse travels at a different speed than other portions of the energy. If enough of the energy travels at sufficiently different speeds over a length of fiber, then preceding optical signals can interfere with trailing optical signals. This is called intersymbol interference (ISI).

There are several causes of dispersion in a fiber. Dispersion will vary based on fiber type, fiber quality, transmitter type, transmitter spectral width, and other factors. Dispersion becomes more significant as the length of fiber span increases. Higher bit-rate systems are generally more negatively impacted by dispersion than lower bit rate systems.

There are three major types of dispersion in optical transmission:

1. **Modal dispersion** (multimode fiber). Adherence to design limits, specifically application supported distances for a particular transmission protocol on a particular type of fiber, will avoid this issue.
2. **Chromatic dispersion** (multimode and single-mode fiber).
3. **Polarization mode dispersion** (single-mode fiber).



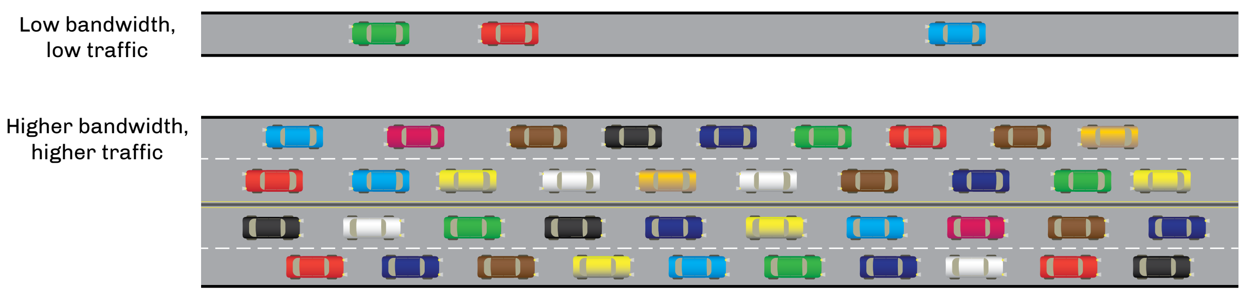
Almost all fi ber communication links experience some amount of dispersion. If the total dispersion is lower than the threshold for the type of transmission (bit rate, encoding, and detection protocol) on the link, then there are no issues. However, if the link is to be upgraded to a higher bit rate or extended in length, the dispersion values may impose a limit on the maximum bit rate. Fiber links must be engineered for dispersion limits as well as att enuation limits.

Bandwidth

In fiber optic communications, bandwidth is a measure of the maximum amount of data that can be transmitted over a link in a period of time, typically one second. It is usually measured in bits per second, i.e., . Megabits (Mb/s) or Gigabits per second (Gb/s). Bandwidth can also be measured in megahertz (MHz), with a rough correlation of one bit per Hz.

Bandwidth usually represents the total capacity of the system and is not necessarily equivalent to link data rate. While it's interesting to think about the potential maximum theoretical bandwidth of a system, there are also practical concerns that limit the system to a throughput level much below the maximum. Standards documents often define system architectures and transmission protocols that dictate the bandwidth of a system, not so much to maximize it, but to ensure interoperability of multiple vendors' equipment at that throughput. Bandwidth can be asynchronous, i.e., it can be different in the forward or downstream direction than it is in the reverse or upstream direction.

The analogy of a highway representing a data link — with the bandwidth represented by the amount of traffic the highway can support —is somewhat useful in thinking about bandwidth. One might get more cars on the highway by building more lanes. One could even build lanes vertically and create a double or triple decker thruway, or one could drive the cars faster. Maybe trucks that carry more data can be substituted for cars. None of these are exactly analogous to increasing data traffic, but it may help one think about it. There are many methods that fiber systems use to increase bandwidth.



With multimode fibers, the bandwidth is the amount of information that can be transmitted effectively over a given distance, usually defined as MHz relative to a kilometer span (MHz-km) at a specific wavelength, e.g., 4700 MHz-km @ 850 nm. Since multimode fiber transmits photons over a variety of modes, the distance that a fiber can transmit a signal before dispersion degrades the signal quality is limited by the data rate. As distance increases, multimode bandwidth decreases.

While single-mode fiber does not have a bandwidth specification, its transmission is limited by the amount of dispersion in the system.

Chapter 2 Discussion

1. Describe the two causes of intrinsic attenuation.

2. Describe why microbending impacts fiber optic light transmission.

3. Describe why macrobending impacts fiber optic light transmission.

Chapter 3

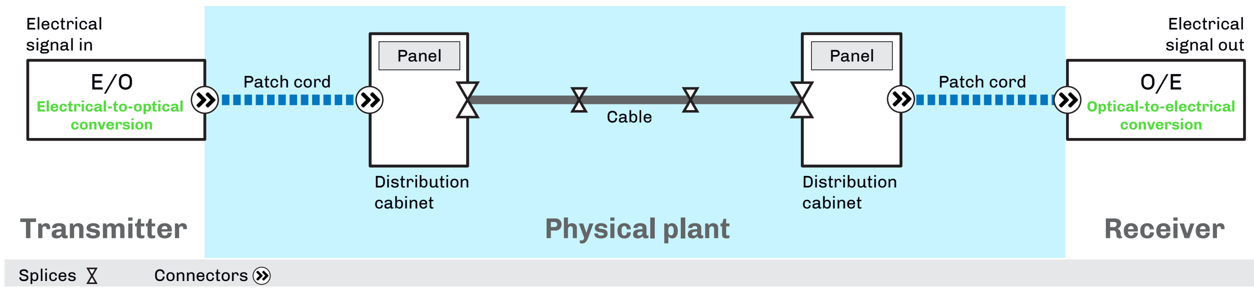
Fiber

By the end of this chapter, you will be able to:

- List and describe the types of multimode fibers
- List and describe the types of single-mode fibers

The Physical Plant

The physical plant encompasses all of the components between the transmitter and receiver that make up the entire fiber optic network.



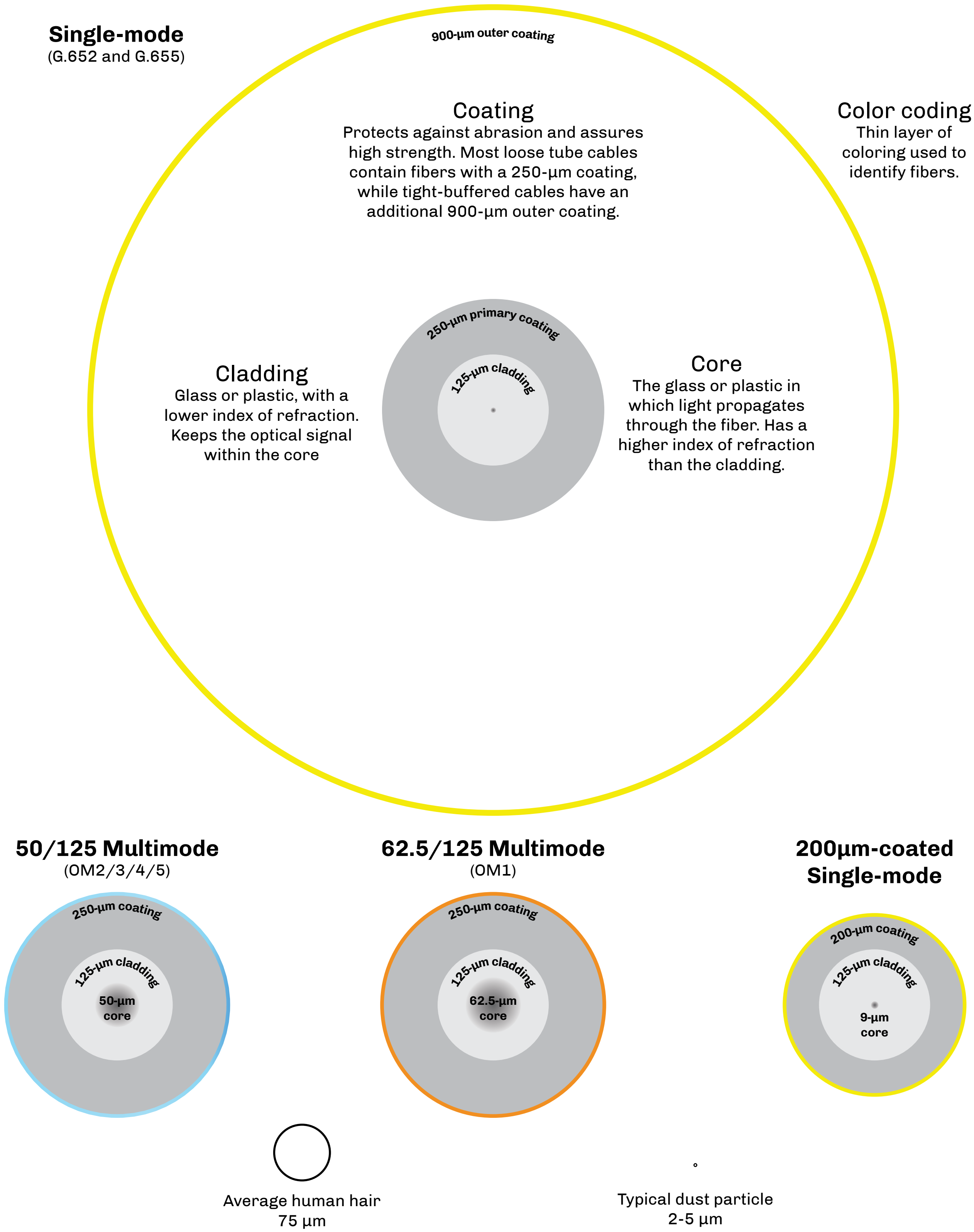
- The infrastructure that makes up the fiber optic network
- The fiber, cable, connectors, splices, panels, and cabinets, et al., that are deployed in the field

The optical fiber acts as a waveguide to route the signal from the transmitter to the receiver. In order to create a continuous waveguide, many segments of optical fiber are joined together. Permanent joints are made with fusion or mechanical splices. Reconfigurable joints are made using fiber connectors.

The fiber is not 100% efficient and loses some power over distance. Splices and connectors also contribute to signal loss where they are installed.

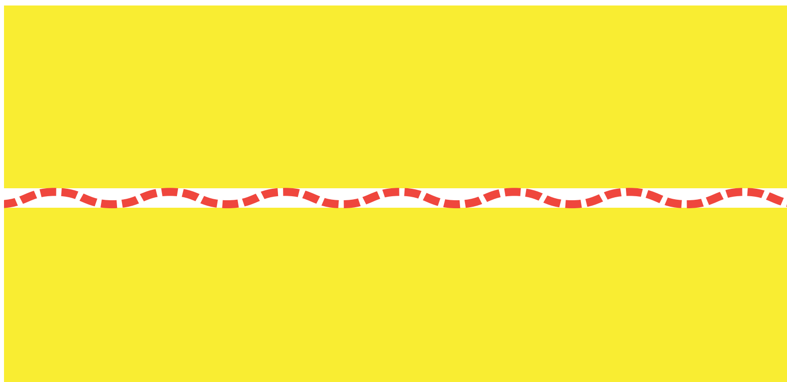
All other components, cable, closures, racks, ducts, poles, etc., serve to either mechanically or environmentally protect the fiber or to assist in routing the fiber within the cable between the transmitter and receiver.

Fiber Comparison

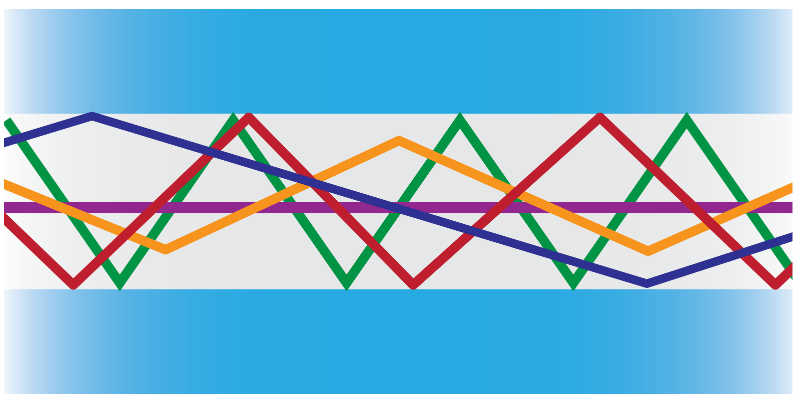


What is a Mode?

- A "mode" is a discrete light path within the core of the fiber between the transmitter and the receiver.
- The number of modes that a fiber will support increases as the wavelength decreases.



Single-mode fibers have a single light path at a single wavelength.



Multimode fibers have multiple light paths (500+).

The ability of an optical fiber to bind or hold light energy and transport it as a mode is determined by physics and can be modeled by some complex mathematical equations. Essentially, multimode fiber will have many solutions to its equations, while the design of a single-mode fiber will restrict the solution set to one.

The design of the fiber does not make it specifically single-mode or multimode. The design only determines that the fiber will exhibit single-mode behavior or multimode behavior through a specific range of wavelengths. For example. many single-mode fibers exhibit single-mode behavior above approximately 1200 nm but exhibit multimode behavior below 1200 nm. If you transmit an 850-nm signal down a single-mode fiber, there will be many modes.

Multimode Fiber

Multimode optical fiber is designed to simultaneously carry multiple light pulses, or modes, each at a slightly different angle of reflection within the core. Multimode fiber is used for relatively short transmission distances (<2 km), because the modes spread out over longer distances (modal dispersion) limiting the overall bandwidth. Multimode fiber systems use lower-cost transmitters such as light-emitting diodes (LEDs).

Advantages

- Lower cost electronics, which leads to lower overall system cost
- Easier to splice and connectorize than single-mode fiber.

Disadvantages

- More attenuation (loss) than single-mode fiber
- Short distances (<2 km)
- Bandwidth limited due to greater modal dispersion (pulse spreading)

Applications

- Local area networks (horizontal and backbone)
- Data centers
- Industrial controls
- Control systems
- CCTV systems
- Campuses
- Security

Multimode Fiber Characteristics

- Bandwidths up to 4,700 MHz-km with OM4 and OM5 laser-optimized fibers.
- Losses of 0.6 dB/km to 3.5 dB/km.
- Core is 50 microns, or 62.5 microns for legacy multimode designs.
- Effective with laser or LED sources.
- Lower costs for components, test equipment, and transmitters/receivers compared to single-mode fiber.
- Higher cost than single-mode fiber.
- Distance limitations due to higher loss and pulse spreading.
- Operates at 850-nm and 1300-nm wavelengths.

Fiber Specifications

Below are the maximum allowable specifications for multimode and single-mode fiber per TIA-568D. The TIA-568 specification is generally applied to campuses and in-building applications.

		S/M (OS1/2)	M/M (OM5)	M/M (OM4)	M/M (OM3)	M/M (OM2)	M/M (OM1)
Core diameter (microns)		8.3	50	50	50	50	62.5
Mode field diameter (microns)	1310 nm	9.3 ±0.5	—	—	—	—	—
Cladding diameter (microns)		125	125	125	125	125	125
Numerical aperture		0.13	0.20	0.20	0.20	0.20	0.275
Attenuation* (dB/km)	850 nm	—	≤3.0	≤3.0	≤2.3	≤3.5	≤3.5
	1300/1310 nm	≤0.4	≤1.5	≤1.5	≤0.6	≤1.5	≤1.5
	1550 nm	≤0.3	—	—	—	—	—
Bandwidth** (MHz-km)	850 nm	—	4700	4700	2000	500	200
	953 nm	—	2470	—	—	—	—
	1300 nm	—	—	—	—	500	500
Dispersion (ps/nm-km)	1310 nm	3.2	—	—	—	—	—
	1550 nm	17	—	—	—	—	—
Primary coating layer (microns)†							
With color code		250	250	250	250	250	250
Without color code		245	245	245	245	245	245

*TIA-568 cabling standard requirement.
**Bandwidth measured using the minEMBc formula.
†200-micron coatings are also seeing use for large fiber count cable to increase fiber counts.

Application Supported Distance

Application supported distance is the maximum transmission distance for a fiber using a specific transmission protocol at a given bit rate.

Fiber mode	100BASE	1000BASE		10GBASE		40GBASE	100GBASE
		850nm	1300nm	850nm	1300nm		
OM1	≤2000m	275m	550m	33m	≤300m	—	—
OM2	≤2000m	550m	550m	82m	≤300m	—	—
OM3	≤2000m	550m	550m	300m	≤300m	100m	100m
OM4	≤2000m	1000m	550m	550m	400m*	150m	150m
OM5	≤2000m	—	—	—	400m*	150m	150m

Legacy Multimode Fibers

Multimode optical fibers were initially optimized to perform with light-emitting diode (LED) sources at 1300 nm. The larger 62.5-µm core size of OM1 fiber represented a compromise between greater modal dispersion from the larger core size and the ability to capture more light from a nondirectional, noncoherent LED source. The core size was narrowed to 50 microns in order to reduce modal dispersion, but the fiber was still optimized for LEDs operating at 1300 nm.

Unfortunately, LEDs in general are limited to modulation speeds below about 1 GHz. They also tend to excite more higher order modes than a laser, resulting in relatively higher modal dispersion. In order to get high-speed operation in a multimode system, it was clear a laser source would be necessary.

Rather than use a Fabry-Perot laser or a distributed feedback laser with a very small spot size suitable for high coupling efficiency into a single-mode fiber, the vertical-cavity surface-emitting laser (VCSEL) was developed. For various reasons, it is easier and cheaper to produce VCSELs optimized at 850 nm. The VCSEL's laser offers very high-speed modulation and less excitation of high order modes (compared to an LED), resulting in drastic improvements in multimode fiber system performance. Therefore, OM3 and OM4 fibers were developed for high-speed operation with these new lasers.

Note: Due to the core mismatch, it is never recommended to connect a 50-µm core fiber to a 62.5-micron core fiber as this results in a connection that is extremely high loss in one direction.

Today, OM1 and OM2 fibers are considered legacy fibers. This means that they are no longer a part of new revisions of standards documentation or the development of new systems.

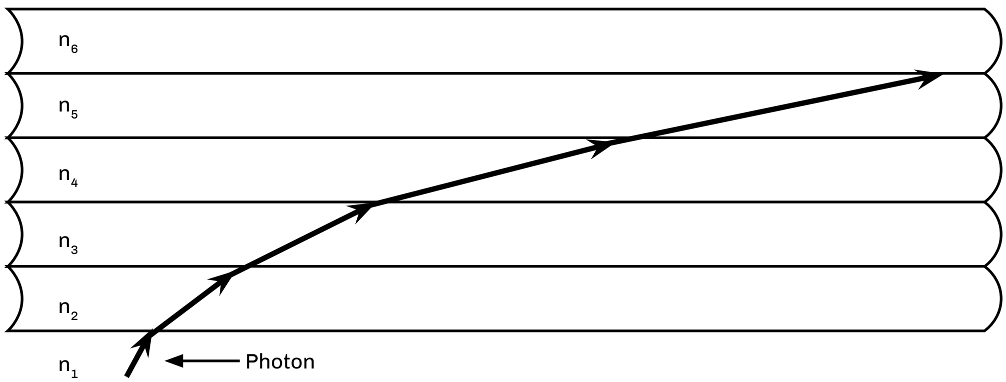
Historical Legacy Multimode Fiber Specifications

Manufacturer		Core size	Index of refraction		Attenuation (dB/km)		Bandwidth (MHz-km)	
			850 nm	1300 nm	850 nm	1300 nm	850 nm	1300 nm
Corning	OM2	50 µm	1.490	1.486	≤2.5	≤0.8	500	500
	OM1	62.5 µm	1.496	1.491	≤2.9	≤0.6	200	500
Prysmian/ Draka	OM2	50 µm	1.482	1.477	≤2.2	≤0.5	1000	1500
	OM1	62.5 µm	1.496	1.491	≤2.6	≤0.5	300	1000
OFS	OM2	50 µm	1.483	1.479	≤2.4	≤0.7	500	500
	OM1	62.5 µm	1.496	1.491	≤2.9	≤0.7	200	500

Multimode Graded-index Fibers

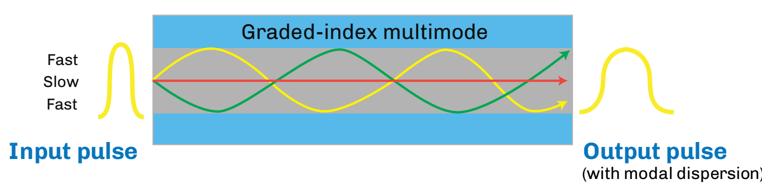
One approach to improving multimode fiber performance is to design the core to reduce modal dispersion.

Instead of simply relying on a single index of refraction (IOR) difference at the core/cladding boundary to reflect the light, a graded-index fiber is constructed with a core that has hundreds of concentric layers of glass between the center of the core and the cladding. Each of these layers has its own IOR so that light is gradually refracted back toward the center of the fiber core.



The regions of the core closest to the cladding have a slightly lower IOR. The highest IOR (lowest velocity of propagation) is found near the axis while lower IORs (highest velocity of propagation) are found in the outermost region of the core. As the velocity of propagation of light in the core is equal to the speed of light in a vacuum divided by the IOR, the lower IOR results in a slightly higher velocity of propagation of light near the outside of the core compared to its axis. A mode would slow down when passing through the inner layers of the core and accelerate when passing through the outer layers. This allows the higher-order modes to arrive at the same approximate time as the axial- or lower-order modes.

While this technique does not completely compensate for modal dispersion, it does maximize bandwidth by reducing modal dispersion. It also makes the fiber more complex and expensive to manufacture than if it had a uniform index of refraction.



Laser-optimized Multimode Fiber Types

Manufacturer	IEC #	Fiber size	Index of refraction		Attenuation (dB/km)		Bandwidth (MHz-km)*		Max distance (meters)**
			850 nm	1300 nm	850 nm	1300 nm	850 nm	1300 nm	850 nm
Alcatel Glight 6933	OM3	50/125	1.482	1.480	≤2.5	≤0.8	500	500	2000
Corning ClearCurve	OM3	50/125	1.480	1.479	≤2.3	≤0.6	1500	500	1000
Corning ClearCurve	OM4	50/125	1.480	1.479	≤2.3	≤0.6	3500	500	1100
Corning InfiniCor SX+	OM3	50/125	1.481	1.476	≤2.3	≤0.6	2000	500	1000
Prysmian MaxCap	OM3	50/125	1.482	1.477	≤2.2	≤0.5	1500	500	550
Prysmian HiCap	OM4	50/125	1.482	1.477	≤2.2	≤0.5	3500	500	550
OFS Laser Wave 300	OM3	50/125	1.483	1.479	≤2.2	≤0.6	1500	500	1000
OFS Laser Wave 550	OM4	50/125	1.483	1.479	≤2.2	≤0.6	3500	500	1040

* Source to fiber coupling variations affect bandwidth-length products. Refer to ANSI/TIA-492AAA and AAAE for information on determining effective modal bandwidth as required by 10-Gigabit applications.

** Gigabit Ethernet specified in IEEE 802.3z for 10 GbE applications, refer to IEEE 802.3ae and manufacturer product specification sheets.

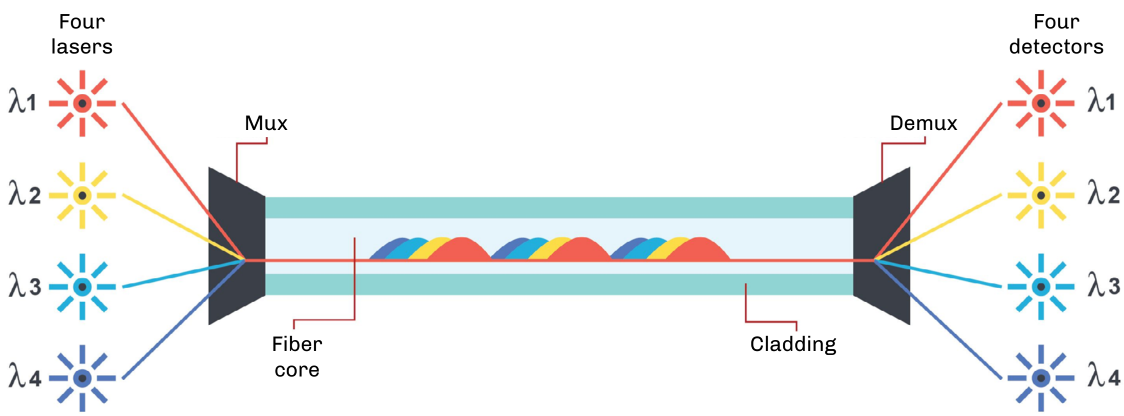
Laser-optimized fiber was developed to work with vertical-cavity surface-emitting lasers (VCSELs) operating at 850 nm.

The highest performance multimode fiber today is the OM4 classification. The attenuation values of this laser-optimized 50/125 fiber are 2.5 dB/km at 850 nm and 0.8 dB at 1300 nm. It is specified with 4700 MHz-km effective modal bandwidth at 850 nm and overfilled bandwidth values of 3500 MHz-km at 850 nm and 500 MHz-km at 1300 nm. “Overfilled” refers to LED operation, while the effective modal bandwidth (EMB) refers to operation with a laser source.

OM5 Multimode Fiber

Transmitting multiple high-speed data streams at differing wavelengths (colors) of light increases the bandwidth or data carrying capacity of a fiber. For example, four VCSEL transmitters each operating at a slightly different wavelength transmit four separate 25 Gb/s data streams. These four streams are combined (multiplexed) into a single fiber. At the receive end, the four wavelengths are separated (demultiplexed) and sent to four separate detectors within the receiver module. This technique permits 100 Gb/s transmission on a single multimode fiber. Accomplishing this with one wavelength is not feasible due to modal dispersion. This technique is known as wideband multiplexing or short wavelength division multiplexing (SWDM).

A new fiber specification was developed to support this transmission technique and is designated OM5 wideband multimode fiber (WBMMF). OM5 fiber is specified to meet the performance characteristics of OM4 at both 850 nm and 953 nm, as compared to OM4 which is specified at only 850 nm. The nominal transmission wavelengths established by the Metro Ethernet Forum are 850, 880, 910, and 940 nm.



Wideband multimode fiber

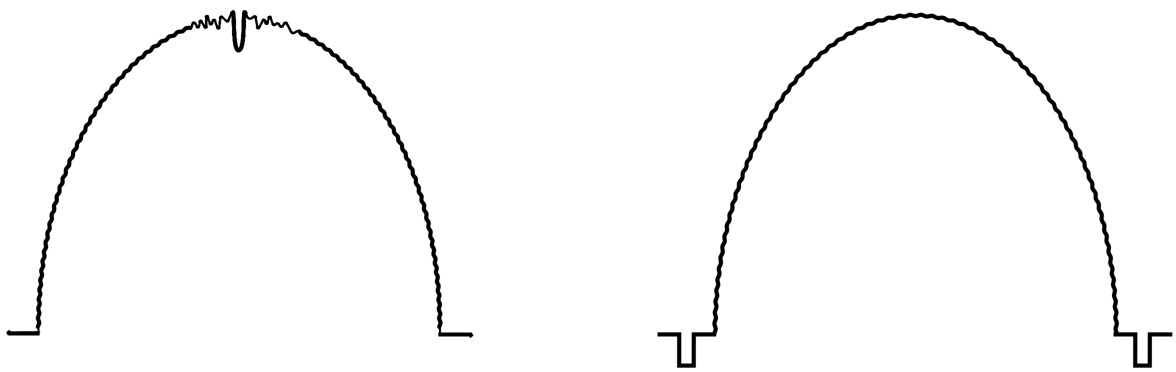
Courtesy OFS

For installers and end users, the only requirement for field testing is to use the standard 850 nm/1300 nm windows. Chromatic dispersion values are in the standards and fiber manufacturers are required to ensure these performance values are met.

- Designed for short wavelength division multiplexing (SWDM)
- Enables 400 Gb/s transmission using 8-fiber technology
- Optimized for 850-953 nm spectrum
- Four wavelength channels assigned
- Testing occurs at 850/1300 nm

Bend-insensitive Multimode Fiber

In a standard multimode optical fiber, the higher order modes will leak into the cladding when the fiber is bent. To reduce the magnitude of this bending loss, bend-insensitive multimode fiber (BI-MMF) is manufactured with an optical trench between the outer modes of the optical core and the cladding. This trench creates a reflective barrier, which keeps the outer modes within the core region when the fiber is bent.



Conventional multimode fiber with centerline dip

Bend-insensitive multimode fiber without centerline dip

Graded-index bend-insensitive multimode fiber profile

While multimode fi ber has always been less sensitive to bends than single-mode fi ber, the minimum bend radius limitation on installed multimode fi bers in buildings has always been an issue. Bend-insensitive fi ber allows for smaller cabinetry and enclosures, increased storage in small spaces, and more elegant routing in buildings.

Fiber manufacturers have turned their att e ntion t o t he p remises a pplications w here g raded-index multimode fi bers could be improved. While the greatest need is for the laser-optimized OM3 and OM4 50/125 fi bers, some fi ber manufacturers are also providing legacy OM1 and OM2 BIMMF fi bers.

Mechanical Specifi cations

Bend radius physical testing originally specifi ed for overfi lled launch conditions was standardized by the TIA-455-62 FOTP and the IEC 60793-1-41 as 100 turns around a 75-mm diameter (or 37.5-mm radius) mandrel for the measurement. Th is has since been modifi ed for EMBc testing to two turns around a 15-mm radius mandrel per ITU-T G.651.1. Further reduction to two turns at 7.5-mm bend radius testing is currently under IEC work group consideration.

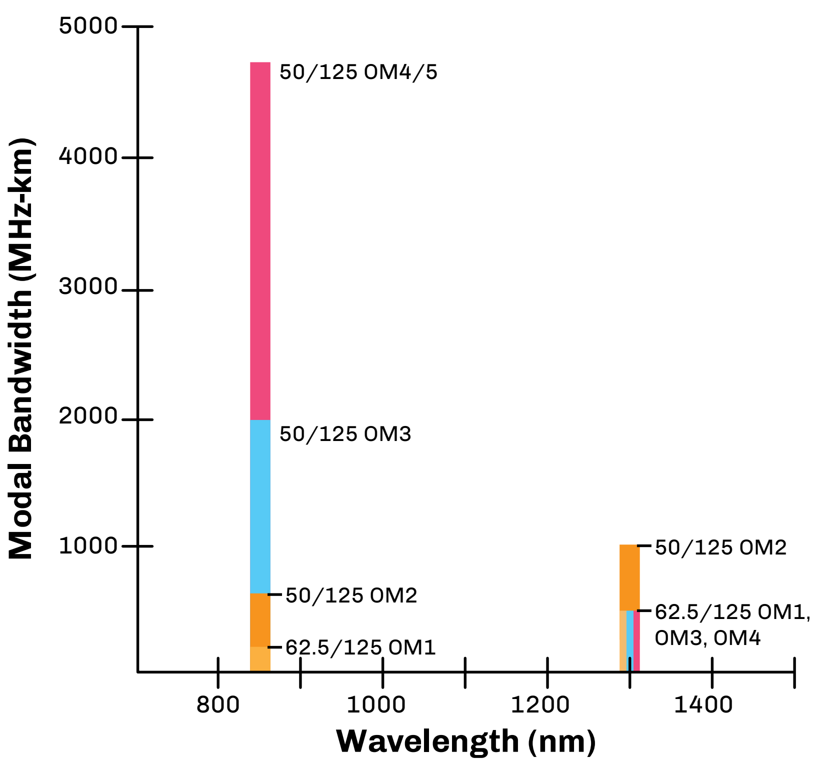
Bandwidth in Multimode Fibers

Bandwidth testing of multimode fiber measures differential mode delay (DMD), which limits the amount of information that can be effectively transmitted. It is performed by the fiber manufacturer using optical time-domain or frequency domain methods as defined in TIA-455-203, 204, and 220 fiber optic test procedures (FOTPs), and in the IEC 60793 standard.

Since modal dispersion in multimode fibers is highly dependent on launch conditions, two different bandwidth performance levels may be specified: one based on an overfilled launch for LED operation; and one based on the effective modal bandwidth (EMB) for operation with the laser.

Launch conditions include:

- Overfilled launch.
  - Legacy OM1/OM2 fibers.
- Restricted mode launch (RML).
  - More accurate than overfilled launch with LEDs.
- Minimum calculated effective modal bandwidth (minEMBc).
  - OM3, OM4, and OM5 fibers.
- Encircled flux.
  - OM3, OM4, and OM5 fibers.
  - Greater accuracy than minEMBc, but more difficult to test installed multimode fiber plant.



Dispersion in Multimode Fibers

Modal Dispersion

Light energy is transmitted in multiple modes. Each mode travels a different path and arrives at the end of the link at a different time.

In multimode fibers, modal dispersion limits effective transmission distance. Because axial modes arrive sooner than higher order modes, individual bits, variations in light amplitude in the time domain, will “spread”.

Modal dispersion is affected by launch conditions.

- An LED “overfilled” launch creates a higher ratio of high order modes, increasing modal dispersion and limiting bandwidth.
- A VCSEL “underfilled” launch creates a higher ratio of lower order modes, decreasing modal dispersion and improving bandwidth.

The total cumulative effect of modal dispersion will define the potential performance of a multimode fiber with a given transmitter type at a given bit rate. This data is usually expressed in a table of application supported distances (ASD) where the operator can easily determine the maximum transmission distance for a given protocol using a given type transmitter over a specified number of fibers.

Chromatic Dispersion

Chromatic dispersion (CD) is the variation in the velocity of light (group velocity) as a function of wavelength. It causes pulses of a modulated laser source to broaden when traveling within the fiber, up to a point where pulses overlap and bit error rate increases. CD is a limiting factor in high-speed transmission and must be properly compensated, which implies proper testing.

CD is affected by the spectral width of the source.

- LEDs have a large spectral width and can cause enough CD to be significant.
- VCSELs have a relatively narrower spectral width, so modal dispersion is by far the dominant cause of dispersion.

Single-mode Fiber

Single-mode optical fiber has only one mode or pathway for the transmission of a light energy. This eliminates modal dispersion as a cause of pulse spreading, resulting in significantly higher bandwidth. Higher-cost laser transmitters are typically required to effectively couple to its smaller 8-9 micron core.

Advantages

- Greater bandwidth
- Less loss
- Greater distances
- Can be optically multiplexed

Disadvantages

- More expensive electro-optics are required, resulting in greater overall system costs

Applications

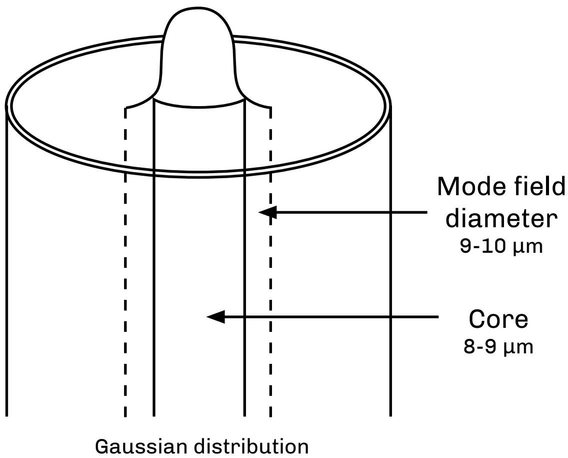
- Telcos
- Telephony users
- FTTx
- Broadband/CATV
- Intelligent transportation systems
- Wide area networks (WANs)
- Data centers

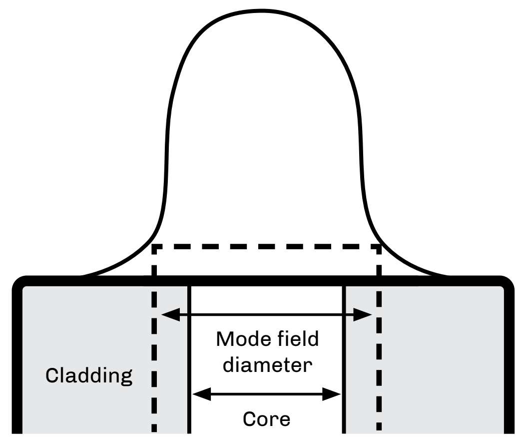
Single-mode Fiber Characteristics

- Typically has a 9-micron core and a 125-micron cladding
- High bandwidth (200-500 THz)
- Low attenuation (0.2 dB/km to 0.4 dB/km)
- Higher costs for connectors, splices, test equipment, and transmitters/receivers
- Operates from 1260 to 1650 nm

Mode Field Diameter

Mode field diameter (MFD) is the diameter of the spot of light transmitted through a single-mode fiber. Unlike multimode fibers where the optical power distribution occurs entirely within the core of the fiber, in single-mode fibers approximately 80% of the light is within the core while the remaining 20% is transmitted in the surrounding cladding.





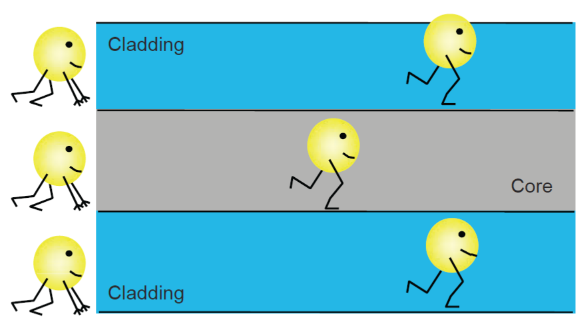
The TIA-455-191 standard calls out how the optical power distribution is determined in single-mode fibers. Fiber/cable specification sheets may call out recommendations for both single-mode core and mode field diameter. The effects of MFD are the following:

1. The larger the MFD, the easier it is to splice and connectorize.
2. The larger the MFD, the more sensitive the fiber is to microbends.
3. The MFD varies depending on the wavelength used.

Specification	Wavelength	Mode Field Diameter
ITU-T G.652	1310 nm 1550 nm	8.6-9.5 ±0.7 µm 9.8-10.7 ±0.5 µm
ITU-T G.655	1550 nm	8-11 ±0.7 µm

4. Because optical energy is traveling in both the core and the cladding of single-mode fibers, the difference in the index of refraction between the core (slower IOR) and the cladding (faster IOR) causes waveguide dispersion to occur. Waveguide and material dispersion combine to create chromatic dispersion.

5. The mode field diameter of a fiber is an intrinsic characteristic at any given wavelength and is usually not of concern to the technician or operator conducting routine operations, e.g., splicing or testing.



Fiber Tolerances

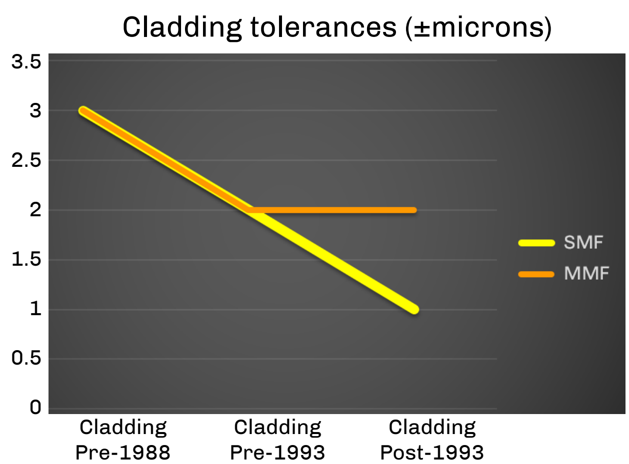
Fiber tolerance values apply everywhere.

All splices and connection losses are affected by tolerances. Splicing or connecting new fibers to older fibers may result in higher losses due to tolerances. While new products have better tolerances, even splicing new fiber to new fiber can result in loss from tolerances. Connector ferrules and splicer V-grooves also have tolerances.

Fiber tolerances affect splice and connector losses and vary with different fiber types, from different ends of the fiber. These tolerances can cause variations in loss measurements such as differing bidirectional measurements, high losses, and OTDR traces that report splices that exhibit gains (known as gainers). Different fiber types have different attenuation and dispersion characteristics, and different manufacturers use different manufacturing processes.

Listed below are a few of the fiber tolerances one must recognize with standard fiber types.

- Cladding O.D. tolerances can vary as much as ±1 micron for single-mode and ±2 microns for multimode.
- Core diameter can vary from one part of the cable to another, as much as 0.7 microns. Core tolerances can vary as much as ±1 micron for single-mode, and ±3 microns for multimode.
- The core/cladding concentricity (how centered the core is) and core ovality (how round the core is) also can vary from fiber to fiber.



Optical characteristics can vary from manufacturer to manufacturer. Several generations of fibers from vendors can each have different characteristics.

	1987	1993	2017
Cladding diameter tolerance	3 µm	1 µm	0.7 µm
Core diameter tolerance	8.7 ±1 µm	8.3 ±1 µm	8.2 ±1 µm
Mode-field diameter	10±1 µm	9.3±0.5 µm	9.2±0.4 µm
Cladding non-circularity	2%	1%	0.7%
Core/cladding concentricity	1 µm	0.8 µm	0.7 µm
Numerical aperture	.11	.13	.14

Single-mode Optical Fiber

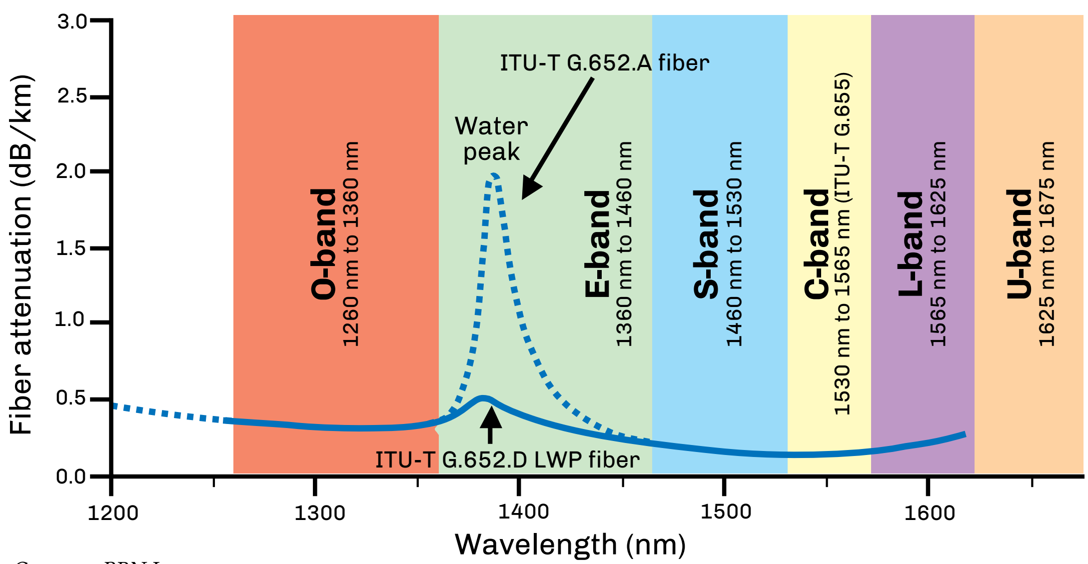
ITU-T G.652D

ITU-T G.652 fiber was the first type of single-mode fiber manufactured, and is the most widely-deployed single-mode fiber by telephone companies, utilities, and multiple service operators (MSOs). It has a typical loss of 0.33 dB/km at 1310 nm and 0.21 dB/km at 1550 nm. Dispersion is optimized at 1310 nm. It has an abrupt index profile change between the core and the cladding.

As the development of lasers operating at wavelengths other than 1310 and 1550 nm opened up the entire optical spectrum between 1260 nm and 1650 nm, manufacturers returned to address the hydrogen (OH) intrusion problem centered around 1383 nm. The presence of excess OH- ions in the fiber can create an increase in attenuation of up to 2 dB/km in the E-band (1360-1460 nm). The result was a new generation of single-mode fibers that had improved attenuation and allowed for transmission in the E-band. These fibers also fall within the ITU-T G.652 recommendation and are designated as G.652D fibers.

G.652D fibers (IEC 60793 OS2) are ideal for transmitting the full spectrum of wavelengths using ITU-T G.694 specified coarse wavelength division multiplexing (CWDM) channels. Though designated by the ITU as reduced water peak single-mode fiber, this variant is commonly called low water peak (LWP) or zero water peak (ZWP) fiber. They have the same manufacturing tolerances as and are compatible with the older G.652 fibers.

It is strongly recommended that network operators document the specific type of fiber contained in their deployed OSP cables.



Courtesy RBN Inc.

Another variant of the G.652 fiber is the G.657 bend-insensitive fiber designed for use inside buildings where tight bends are common. There are several methods to manufacture this fiber and adjustments to fusion splicers may be required to obtain the lowest splice loss values.

- G.652 (IEC 60793 OS1) standard SMF.
- G.652D (IEC 60793 OS2) single-mode.
  - Designed to minimize attenuation and open up CWDM wavelengths in the E-band.
  - Physically document where installed for future CWDM use.

Single-mode Optical Fiber

ITU-T G.657

With dense populations of distribution and drop cables installed into networks and premises, space limitations became a challenge for optical fiber manufacturers. In 2002, the first type of fiber to address these issues was developed, and it was soon standardized in the ITU-T G.657 "Bending Loss Insensitive Single-mode Optical Fiber and Cable for the Access Network" recommendation. ITU-T G.657 specifically calls out the following:

> *"Class A contains the recommended attributes and values needed to support optimized access network installation with respect to macrobending loss, while the recommended values for the other attributes still remain within the range recommended in G.652.D."*
>
> *"Class B contains the recommended attributes and values needed to support optimized access network installation with very short bending radius applied in fibre management systems and particularly for in- and outdoor installation. For the mode-field diameter and chromatic dispersion coefficients, the recommended range of values might be outside of the range of values recommended in [ITU-T G.652]."*

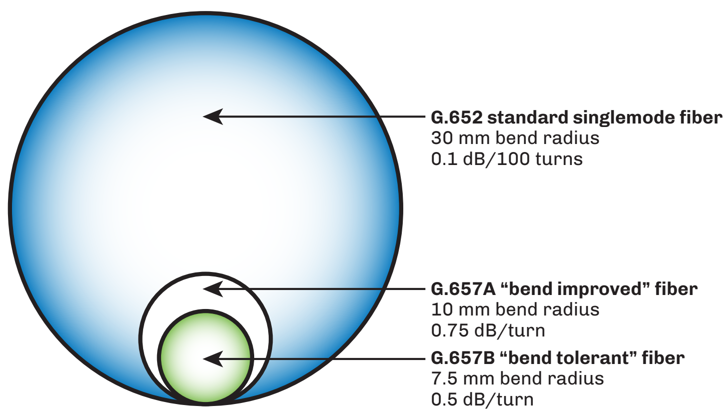
Bend-insensitive fiber (BIF) is ideal for FTTB installations due to its ability to handle smaller bend radius requirements. They are used in high-density applications, low count cables, cable management products, or in-building applications.

Class A

- 1260 to 1625 nm
- G.652D with improved bending loss
- Tighter dimensions
- Smaller MFD

Class B

- 1310, 1550, and 1625 nm
- Restrictive distances
- No water peak specification
- PMD not specified



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Macrobend Loss

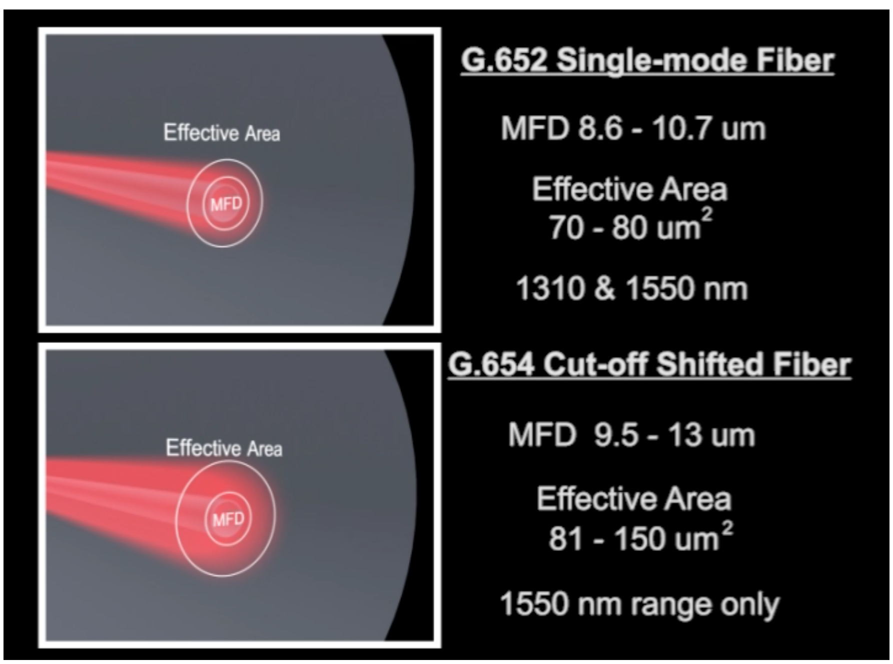
Detail	G.657.A1		G.657.A2			G.657.B2			G.657.B3		
Radius (mm)	15	10	15	10	7.5	15	10	7.5	10	7.5	5
Number of turns	10	1	10	1	1	10	1	1	1	1	1
Maximum at 1550 nm (dB)	0.25	0.75	0.03	0.1	0.5	0.03	0.1	0.5	0.03	0.08	0.15
Maximum at 1625 nm (dB)	1.0	1.5	0.1	0.2	1.0	0.1	0.2	1.0	0.1	0.25	0.45

Single-mode Optical Fiber
ITU-T G.654

The ITU-T G.654 cutoff-shifted fiber, also known as ultra low loss (ULL) fiber, has attenuation as low as 0.16 dB/km. This fiber supports single-mode operation in the 1550-nm wavelength region and transmission in the C-band, L-band, and U-band. It is ideal for submarine and terrestrial long-haul applications that may have up to 400 kilometers between repeaters.

Because these applications also involve high optical power levels, mitigating nonlinear effects is critical to successful operation. G.654 fiber has a wide effective area, which decreases the spatial energy density and the fiber's susceptibility to nonlinear effects, primarily self phase modulation and four wave mixing. In G.654 fiber, the effective area is typically in the range of 120 square microns, 50% larger than conventional fiber, allowing greater total power levels to be coupled into the fiber.

- Also known as low attenuation fiber.
  - 0.16 dB/km.
- Transmits in the C-band, L-band, and U-band.
- Ideal for long-haul applications with up to 400 km between repeaters.
- Mitigating non-linear effects is critical.
- Wide effective area.
  - Typically 120 square microns.
  - Greater power levels can be coupled for longer spans.
  - Reduces non-linear effects and the effects of micro and macro bending.

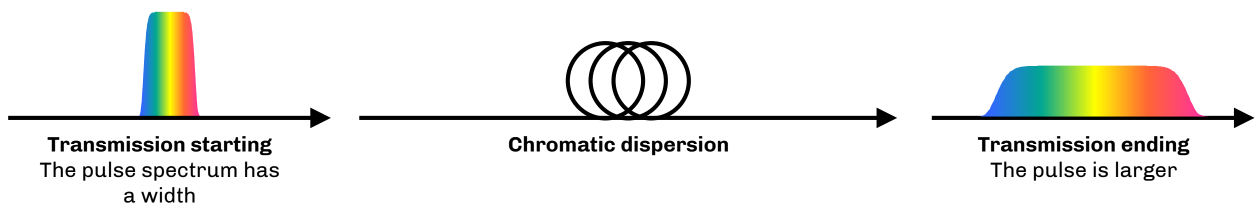


Dispersion in Single-mode Fibers

Chromatic Dispersion

Chromatic dispersion (CD) is the term for the pulse spreading or differential delay of an optical signal in a fiber caused by different velocities of propagation with respect to wavelength. It causes pulses of a modulated laser source to broaden when traveling within the fiber, up to a point where pulses overlap and bit error rate increases. CD is a limiting factor in high-speed transmission and must be properly compensated, which implies proper testing.

CD specified in ps/nm-km, where a picosecond (ps, or one trillionth of a second) represents the magnitude of the differential delay of wavelengths separated by 1 nm over a nominal 1 km distance traveled.



- The spreading of the light pulse due to differences in velocities of propagation at which various wavelengths of light travel
- Naturally occurring property of the glass
- G.652 (OS1) and G.657 SMF have zero dispersion near 1310 nm

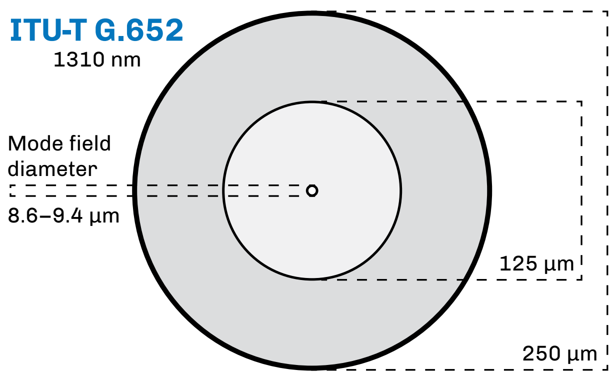
Material dispersion is the principal component of CD. The refractive index of silica is wavelength-dependent. Therefore, different spectral components (i.e., colors) of the source output will travel at slightly different speeds. A laser with a wide spectral width will experience more dispersion than a laser with a narrow spectral width. Manufacturers will seldom publish the laser spectral width but instead will specify, e.g., “this laser transmitter and receiver pair is rated up to 80 km of G.652 chromatic dispersion”.

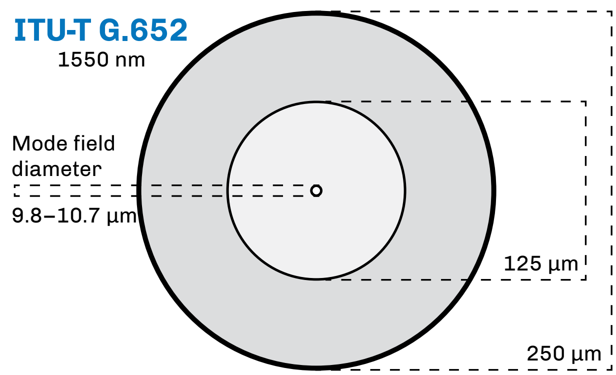
In a single-mode fiber, some of the light energy travels in the core and some in the cladding based on the mode field diameter of the fiber at a given wavelength. The core and cladding have different IORs, which causes the two components to travel at different velocities. The actual ratio of the core/cladding energy is wavelength dependent, so this would vary with wavelength as well. This is termed waveguide dispersion. The sum of waveguide dispersion and material dispersion is equal to the total chromatic dispersion of a fiber.

Note: Chromatic dispersion is also a limiting factor in multimode fiber performance primarily due to the wide spectrum of LED sources. However, it is not specified separately.

Single-mode Optical Fiber

ITU-T G.652

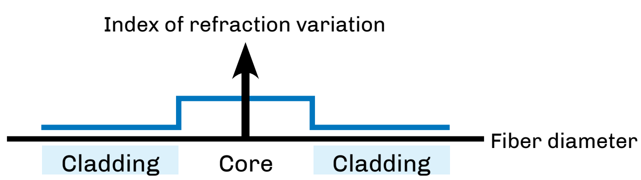




ITU-T G.652 fiber, often referred to as standard single-mode fiber (SSMF), was the first type of single-mode fiber manufactured. It is the dominant single-mode fiber used by telephone companies, utilities, and for campus applications. It is referred to as OS1 or OS2 fibers in IEC 60793. The OS1 designation encompasses covers all G.652 fibers, while OS2 only refers to the low water peak G.652 fibers only.

G.652 is a dual window (1310/1550 nm) fiber that is dispersion optimized for transmission around 1310 nm. It has a distinct index profile change between the core and the cladding.

Courtesy Draka

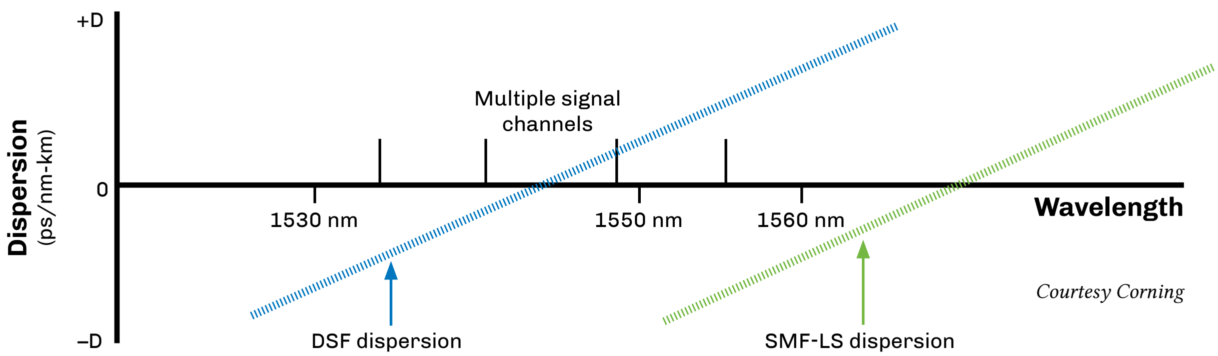


Index of refraction variation for SSMF

Manufacturer		Mode field diameter (microns)		Attenuation (dB/km)			CD [ps/(nm•km)]		
		1310 nm	1550 nm	1310 nm	1550 nm	1625 nm	1310 nm	1550 nm	1625 nm
Corning	NexCor	9.4 ± 0.4	10.6 ± 0.5	0.35	0.20	0.23	—	<18	<23
	SMF28	9.2 ± 0.4	10.4 ± 0.8	0.35	0.22	N/A	—	—	—
	SMF28E	9.2 ± 0.4	10.4 ± 0.8	0.35	0.22	0.23	—	<18	<22
OFS	AllWave™	9.2 ± 0.4	10.4 ± 0.5	0.34	0.21	0.24	—	—	—
	Depressed cladding	8.8 ± 0.5	9.7 ± 0.6	0.40	0.25	—	—	—	—
	Matched cladding	9.2 ± 0.4	10.4 ± 0.5	0.35	0.25	—	—	<18	—
Prysmian	BendBright	9.0 ± 0.4	10.1 ± 0.5	0.35	0.21	0.23	—	<18	<22
	ESMF	9.0 ± 0.4	10.1 ± 0.5	0.35	0.21	0.23	—	<18	<23
	6900	9.0 ± 0.5	10.2 ± 1.0	0.35	0.25	—	—	—	—
	6901	9.0 ± 0.4	10.2 ± 1.0	0.34	0.21	—	—	—	—
	267E	9.3 ± 0.4	10.5 ± 1.0	0.38	0.23	—	—	—	—
Sumitomo	PureBand	9.2 ± 0.4	—	0.33	0.19	0.22	—	<18	<22
	PureAccess	8.6 ± 0.4	—	0.35	0.22	—	—	<18	

Single-mode Optical Fiber
ITU-T G.653

ITU-T G.652 dispersion-shifted fiber (DSF) was designed with the zero dispersion wavelength near the 1550-nm region. The design goal was to take advantage of lower attenuation in the 1550-nm region without having to compensate for its relatively high CD of G.652 at 1550 nm. G.653 was ideal for single wavelength transmission in very long haul networks. Unfortunately, when attempting to use multiple wavelengths, the very low CD caused the wavelengths to exchange energy between them, aggravating four wave mixing.



Courtesy Corning

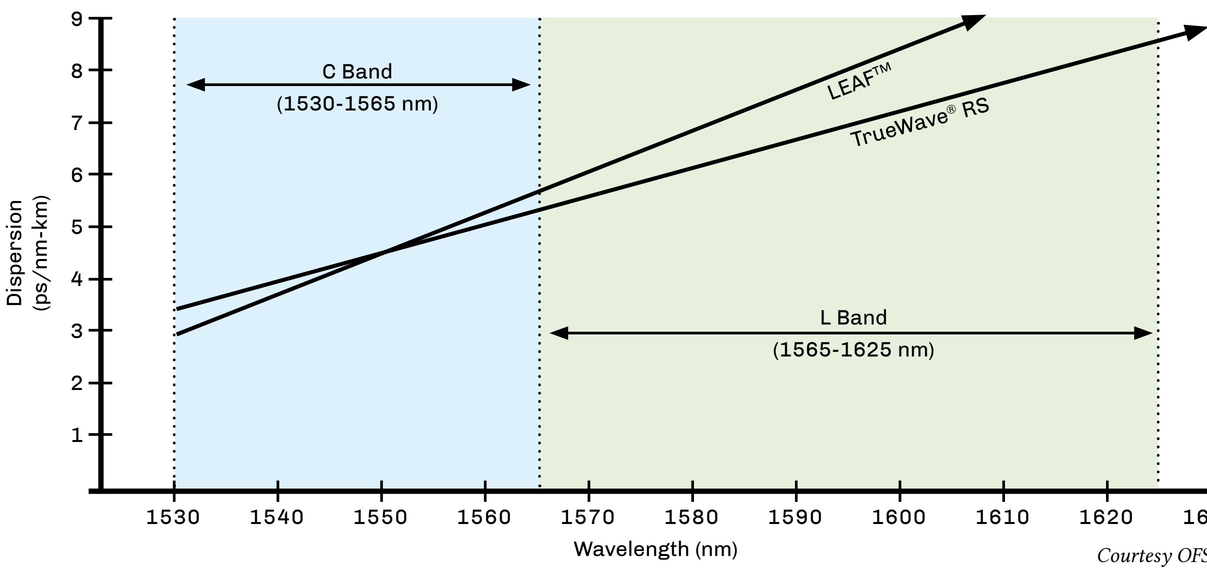
- Dispersion-shifted into low-loss 1550-nm window.
- Obsoleted by ITU-T G.655.
- Aggravated four wave mixing.

Single-mode Optical Fiber

ITU-T G.655

The G.655 nonzero dispersion-shifted (NZDS) fiber was designed for use with DWDM and optical amplifier technologies operating in the C-band near 1550 nm. It is predominantly used by long haul carriers, competitive local exchange carriers (CLECs), and multiple service operators (MSOs). G.656 fiber was designed for use with CWDM and DWDM transmission. Both are attenuation and dispersion optimized at 1550 nanometers. A small amount of positive or negative dispersion is added at 1550 nm, allowing all channels to move at slightly different speeds and reducing the magnitude of four wave mixing.

Some primary differences when comparing G.65x fibers to G.652 fibers are their typically smaller cores and mode field diameters.



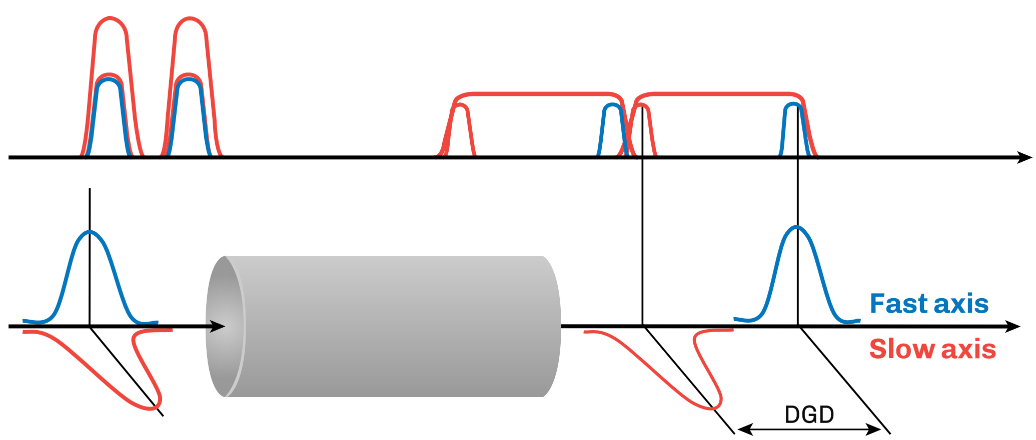
Courtesy OFS Optics

Manufacturer		Mode field diameter		Attenuation (dB/km)		
		1310 nm	1550 nm	1310 nm	1550 nm	1625 nm
Corning	Leaf	N/A	9.5 ± 0.5	N/A	0.22	0.24
	LS	N/A	8.4 ± 0.5	0.5	0.25	N/A
	MetroCor	N/A	8.1 ± 0.5	0.5	0.25	0.25
Fujikura	FutureGuide LA	N/A	9.6 ± 0.4	N/A	0.22	0.25
OFS	TrueWave Reach*	N/A	8.6 ± 0.4	N/A	0.22	0.24
	TrueWave RS™	N/A	8.4 ± 0.6	0.39	0.22	0.24
Prysmian	TeraLight™	N/A	9.2 ± 0.5	0.38	0.25	0.28
	TeraLight Ultra	N/A	9.2 ± 0.5	N/A	0.22	0.25
	TeraLight Metro	N/A	9.2 ± 0.5	0.40	0.25	0.28
Sumitomo	PureGuide	N/A	9.2 ± 0.5	N/A	0.22	0.25
	PureMetro	N/A	8.3 ± 0.5	0.40	0.22	0.25

Dispersion in Single-mode Fibers
Polarization Mode Dispersion

Polarization mode dispersion (PMD) is the term for the pulse spreading that occurs as a result of light energy of a given wavelength traveling at different states of polarization that are propagating at different velocities. Fiber geometry, stresses, or vibration, *et al.*, can cause light traveling at different states of polarization to travel at different speeds. In this case, that fiber is said to be birefringent — having more than one index of refraction. PMD is usually modeled mathematically as a difference in velocities of light traveling it to orthogonal polarizations, e.g., the X axis and the Y axis.

The primary cause of PMD in a fiber is poor geometry (ovality) at time of manufacture. Other major causes include post-installation stresses, galloping, Aeolian vibration due to wind, or vibration of a supporting structure, e.g., a bridge, due to vehicular traffic.



Higher PMD values were more common in fibers of early manufacture and high PMD fibers were represented statistically dependent on overall consistency and quality of fiber manufacture. External stresses induced after manufacture can also aggravate PMD. Because some statistical percentages of all fibers exhibited high PMD, high PMD fibers are found as a statistical percentage of all fibers in a cable. That is, the PMD values of individual fibers in a single fiber cable can vary greatly.

The major figure of merit for PMD is mean differential group delay (DGD). Any given transmission protocol and speed will generally have a corresponding PMD tolerance or limit. For example 10 Gb/s SONET transmission has a PMD limit of 10 ps mean DGD, while 10 Gb/s Ethernet transmission has a PMD limit of 5 ps mean DGD. PMD is not generally compensated for in the way that CD is, but some new high-speed modulation formats are PMD tolerant. Coherent detection with digital signal processing can compensate for many picoseconds of PMD.

Student Notes

Chapter 4
Cable

By the end of this chapter, you will be able to:

- List the colors used for single-mode and multimode cordage
- Describe the structure and components of an optical cable
- Describe the differences between indoor and outdoor cables

Cable Designs

Fiber optic cables are designed to protect the internal fibers while providing an organized structure for terminations and routing. The cabling process bundles fibers in a tough, resistant structure to address different applications that require different cable jackets, internal structures, and components. They must protect against extreme weather conditions and may be strengthened to provide resistance to high tensile loading or armored to prevent attacks from rodents and other animals.

Cables are divided into two broad categories: outdoor and indoor. With indoor cables, the main concern is complying with national electric and fire codes. These codes strictly regulate the types of materials that can be used in cable to reduce flame spread and the evolution of toxic smoke in the event of a fire.

Loose Tube (Loose Buffered)

In loose tube cables, the 200/250-micron coated optical fibers or fiber ribbons are unrestricted within the buffer tube. This allows the fibers to be slightly longer than its confining cavity and to move within the cable when temperature variations lead to expansion and/or contraction.

In order to block the ingress and axial migration of water, filling material may be used in the buffer tube, or flooding material may be used in the cable core or sheath interface. In older loose-buffered designs, the fiber's buffer tube is usually filled with a viscous gel compound that repels water. Newer cable designs often use powders or tapes that restrict water intrusion. If water gets into the cable structure and freezes, it can increase the fiber's attenuation to unacceptable levels.

Loose buffering comes in two major styles (stranded or unitube) and is used for armored, indoor/outdoor, ADSS, OPGW, and FTTx drop cables.

Tight Buffered

Distribution — The smallest common cable type, these are mostly used inside or in between buildings in campus applications. In buildings, the cable is usually found in riser applications and must meet national electrical codes. The use of sub-groups allows for a high count of optical cables. Distribution cables have up to with 3,456 fibers using a ribbon structure. They do not have individual strength members.

Breakout — In breakout style, each 900-µm coated fiber has its own aramid strength member and outer jacket. Breakout cables are larger and more costly than distribution styles due to the amount of aramid yarn. They are very good for industrial applications. Cordage used in patchcords and jumpers are breakout style.

Cable design objective: To isolate the fiber from the cable structure while maintaining practicality of design.

Installation	Operation
Code requirements Pulling tension Conduit/subduct size Fiber access Ease of connectorization Cost Bend constraints 20 x outside diameter (O.D.) of cable	Installed tension Bend constraints Environmental exposure Temperature, wind, moisture/ice, toxicity Reliability Useful life Required optical properties

Cable Materials and Structure

Cable jackets require a variety of materials to best serve the environment in which they will reside. These materials offer protection from mechanical, thermal, chemical, and other environmental concerns.

Jacketing Materials

Polyethylene (PE)	Resistant to moisture, weather, and abrasions. Good electrical properties over a wide temperature range. The standard jacket material for outdoor fiber optic cables.
Polyvinylidene fluoride (PVDF)	Fire-retardant and low smoke; used for plenum cables.
Polyurethane (PU)	Excellent abrasion resistance. Used in raceways and duct environments.
Polyvinyl chloride (PVC)	Flame and oil resistant, flexible, and somewhat rugged. Used in both indoor and outdoor cables.
Teflon™*	A jacketing material offering excellent properties in all cable categories with the exception of radiation environments. Used to meet flame, smoke, and toxicity codes, Teflon cable is more costly than other cable materials.

Structural Elements

Aramid yarn	Commonly termed as a strength member, it is a fibrous material, i.e., Kevlar™*, that protects layers of the cable structure from damage and provides tensile strength to the optical cable. It also provides strain relief for fiber optic connectors.
Armoring (buried cable)	Interlocked or corrugated steel armor is most common, offering protection from rodent attack and crushing forces. NEC Article 250 and NESC Section 9 consider cable with armor to be conductive and must be bonded and grounded. Shielding tape contains a highly-conductive metal such as aluminum or copper primarily for its electrical properties. Armoring tape contains a metal with lower conductivity such as stainless steel for mechanical protection of the cable core.
Buffer jacket (tube)	Protects fiber from moisture, chemicals, and mechanical stresses placed on cable during installation, splicing, and over its lifetime.
Solid strength member	Can be in the cable center or on two sides in the cable jacket. Provides strength and stability to the cable structure. Generally a dielectric material like fiberglass rod and possibly covered with a PE or PVC. When placed on the sides of the cable, the cables will have a preferential bend direction.

Gels, Powders, and Tapes

To repel water intrusion, most outdoor loose tube cables have replaced gel with water absorbents such as water-swellable powder, tapes, and yarns. These have less associated costs, and simplify the cable preparation process for the technician.

Indoor Optical Cables

Plenum and Riser Cables

The National Electrical Code (NEC) and the CSA's Canadian Electrical Code (CEC) discuss indoor optical cables with a prime focus on fire and smoke resistance for plenum and riser areas. The NEC code has designated requirements for cables that will create less smoke and resist flame better than similar PVC or PE cables, without the use of metal conduits.

- **Plenum:** The return of air handling space located between a roof and a dropped ceiling.
- **Riser:** Cables installed in vertical runs that penetrate more than one floor, or cables installed in vertical runs in a shaft.
- **General purpose:** Cables unsuitable for use in riser and/or plenum areas.

NEC Article 770 recognizes three types of optical cables and calls out markings for cables that meet NEC listing requirements for flame resistance and low-smoke emission:

- Conductive — Those that contain metallic conductive elements
- Nonconductive — Those that do not contain metallic conductive elements
- Composite — Those with both electrical and optical conductors

Marking	Type	CSA	UL
OFC	Conductive optical fiber cable		UL 1581
OFCP	Conductive optical plenum cable	FT 6	UL 910
OFCR	Conductive optical riser cable	FT 4	UL 1666
OFCG	Conductive optical fiber general-purpose cable	FT 4	
OFN	Nonconductive optical fiber cable		UL 1581
OFNP	Nonconductive optical fiber plenum cable	FT 6	UL 910
OFNR	Nonconductive optical fiber riser cable	FT 4	UL 1666
OFNG	Nonconductive optical fiber general-purpose cable	FT 4	

Note: Telcordia GR-409 provides technical requirements and characteristics for indoor optical cables.

Because no conduit is required for plenum cables, it is easier to route cables, creating a cost savings. Other benefits from this cable type are reduced weights on ceilings or fixtures, easier configuration, and flexibility for local area networks (LANs) and computer data systems. Floor penetrations that require types OFNR or OFCR shall contain only cables suitable for riser use.

NEC Article 770-48(A)

The 50-foot (15-meter) rule:

In sections 770-48(A) and 800.48 of the NEC, it is stated that no more than 50 feet (15 meters) of measured unlisted conductive and nonconductive outside plant cables shall extend into the structure and should transition (as practical) to inside listed (rated) cables. There are several exceptions listed to this rule in the NEC.

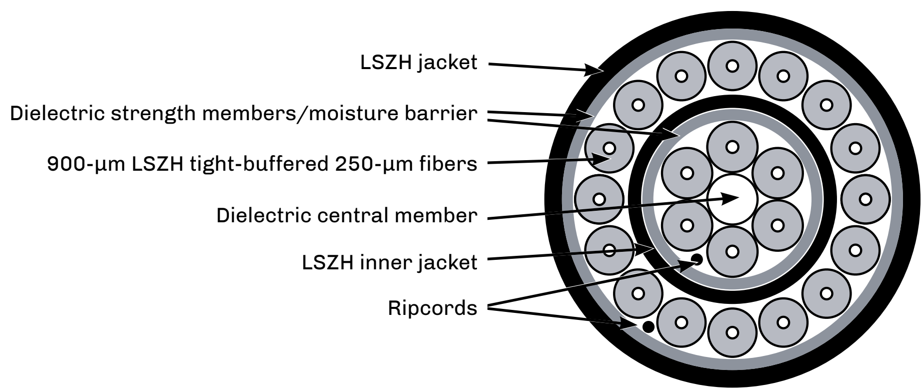
NEC Article 90.2 lists some exceptions, including electric utilities, communications utilities, and mines.

Low Smoke Zero Halogen

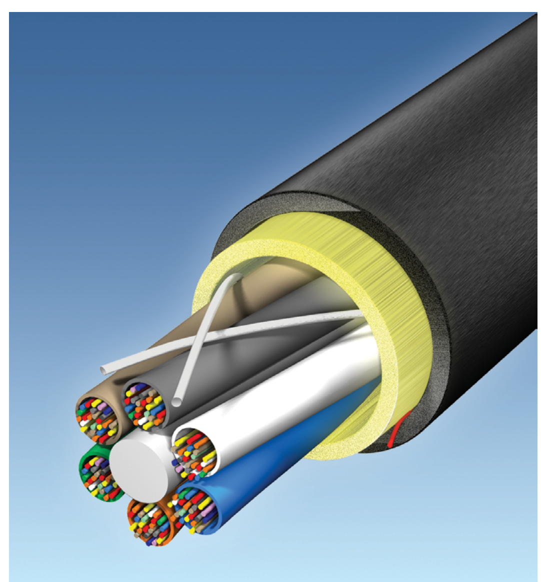
Low smoke zero halogen (LSZH) cable materials are common for international installations and seeing increased usage in the United States. Utilized in confined areas, this material is environmentally stable at low temperatures and resistant to wet locations.

Due to their chemical make-ups, cable jacket materials emit a variety of environment-affecting substances when burned. Chlorine, heavy metals and plasticizers are just a few of the residual by-products left over from the intense heat emitted from the plastics manufactured into the various structures of a cable. Hence, the development of LSZH materials.

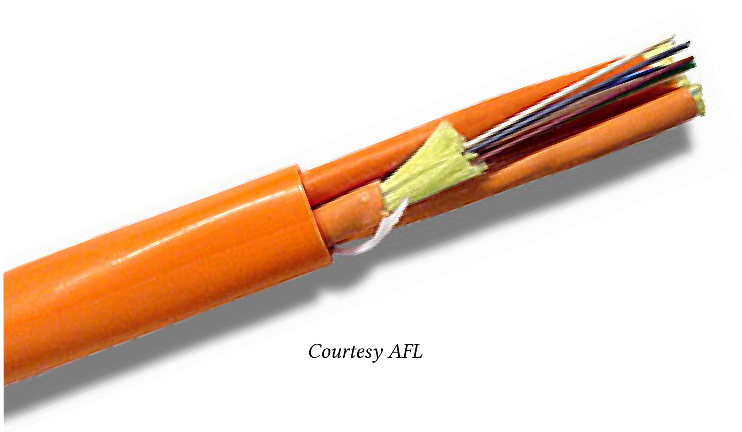
LSZH cabling materials contain flammable polymers including high amounts of metal hydrates (a chemical combination high in water molecules). When burned, the hydrates release water that reduces the flame through a heat-absorbing process, retarding the spread of fire and smoke and the production of fire by-products.



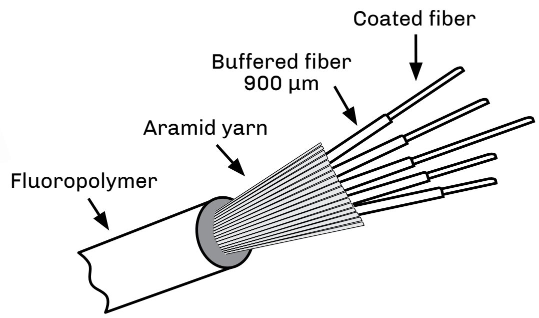
- International standard for indoor cables.
- Zero halogen means removing halogens such as chlorine and fluorine from jacket compounds.
- Retards flame spread and reduces smoke.
- Specified by IEC 60332, 60754, and 61034 standards.
- Will be seeing increased usage in the United States.



Distribution Cables



Courtesy AFL



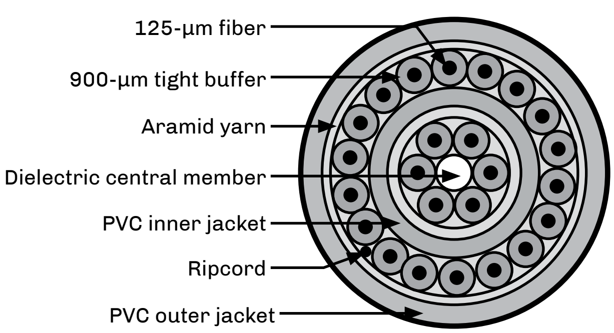
Note that the aramid yarn is outside the fibers.

Used mostly in indoor plenum (OFNP), riser (OFNR), and low smoke zero halogen (LSZH) building environments, distribution cables are a tight-buffered cable design that incorporates 900-µm coated fibers. There are two basic styles: the standard distribution cable, in which all of the 900-µm fibers are surrounded by aramid yarns, and the sub-unit distribution cable, which has two or more distribution cables under the same outer jacketing. A 144-fiber sub-unit cable would have 12 color-coded sub-groups of 12 fibers each.

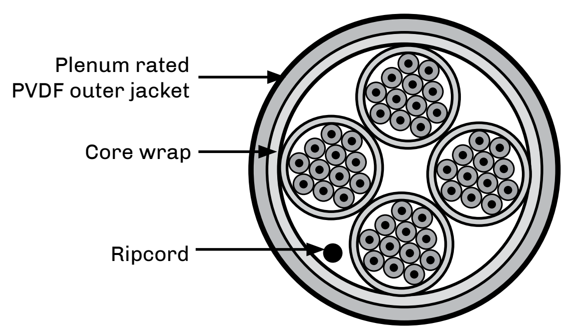
Most indoor applications use the standard distribution cable due to its small diameter and small bend radius. In applications where multiple fibers are being dropped from the cable, the sub-unit distribution cable allows access to individual groups of fibers. Each of the sub-unit outer structures is color-coded to comply with the TIA-598 color code standard. For example, the first group of 12 fibers would have a blue jacket and the second group would have an orange jacket, etc.

Distribution cables have the smallest diameter of the tight-buffered cable designs, allowing them to be used in tight or space-limited locations. While most applications of distribution cables are premises-related, indoor/outdoor styles are also available for substations. These provide a cost benefit by eliminating the need for a splice or cross-connect within 50 feet of a building entrance. For service providers using single-mode fibers, this allows for preterminated patch panels to be installed with a length of fiber cable that can be spliced at the outside plant entrance vault. For premises applications, this would save two splice or connection points, providing both cost and attenuation benefits.

Distribution cable may also be known as non-breakout style cable.



Double jacketed distribution cable



Sub-unit distribution cable

Interlocking Armor Cable

This cable structure is manufactured with a jacketed aluminum outer structure to provide additional protection for indoor or indoor/outdoor breakout or distribution cables. The interlocking armored cable provides ruggedness and flexibility. Because of this, the cable does not require a conduit and can be installed easily into raceways or areas where space is limited. The cable structure also protects against rodents and heavy duty industrial applications. Due to the metallic structure of the cable, it must be grounded per NEC requirements. The cable is available with plenum (OFCP), riser (OFCR) and LSZH listings.

- Features jacketed metallic structure.
  - Rugged yet flexible.
  - OFCP, OFCR, and LSZH jackets.
- Grounding is required.

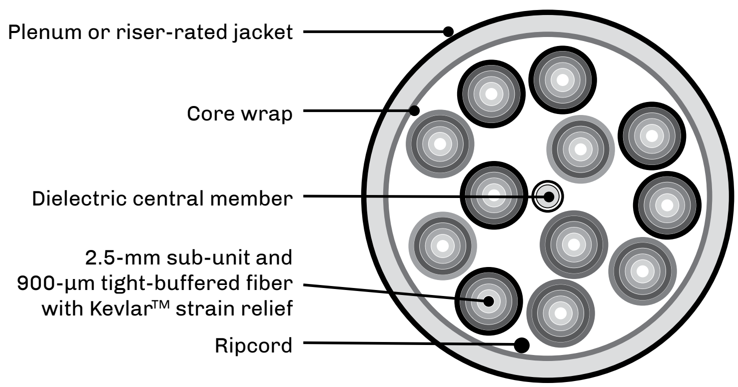
Breakout Cables

The breakout cable design offers a heavy-duty rugged cable for shorter network applications. This may include local area networks (LANs), data communications, utility substations, video systems, and process control environments.

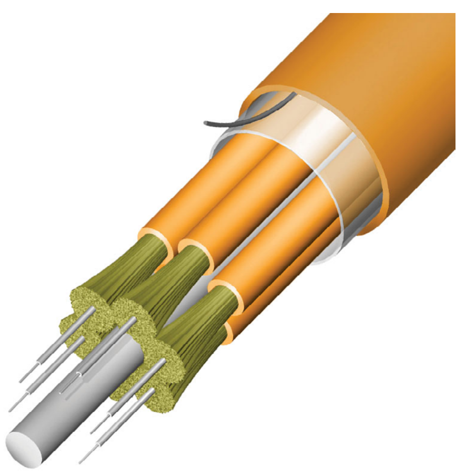
Breakout cables feature a tight buffered design with individual aramid yarn strength members surrounding each 900-micron fiber. As each optical fiber has its own strength member, this style is ideal for direct termination with optical connectors. However, these cables are usually heavier and physically larger than telecom types with equal fiber counts. They have higher tensile strengths and greater crush resistance values than distribution cables.

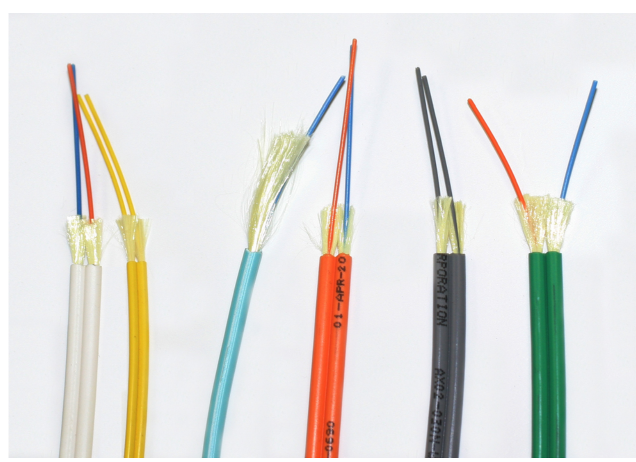
The term “breakout” defines the key purpose of the cable: that one could breakout several fibers at any location and route the other fibers elsewhere. For this reason breakout cables should be color-coded for ease of identification. Because this cable is used in environments where building and safety codes may require plenum- or riser-rated cable jackets, breakout cables are designed to meet national electric codes (NEC).

Most types of cordage used in jumpers, patchcords, and pigtails are breakout cable designs. For users planning on direct connectorization, it is key to match the subunit’s outside diameter with appropriate plug (rear assemblies) for proper strain relief.



12-fiber breakout cable

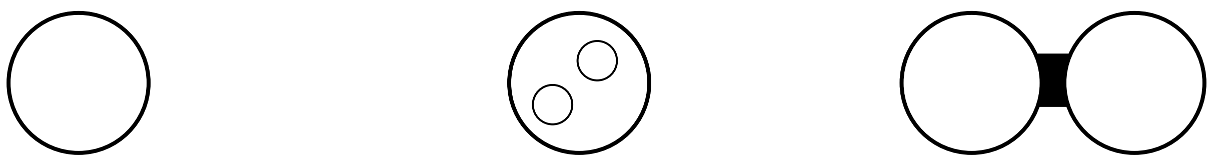




Fiber Optic Cable Cordage

The need to provide a cable structure with standardized geometries and structures for connector applications was recognized early in the history of fiber optics. Once fiber optics moved from the lab to the users' environment, the need for cross-connecting and routing optical fibers to terminal equipment was critical.

The cable had to feature flexibility, ruggedness, and meet applicable building codes all while protecting the internal optical fiber. Cable and connector manufacturers quickly standardized cordage using the 3-mm O.D. jacket for standard connectors and 1.6 and 2 mm for small form factor connectors. While there are several terms for these cables, the basic requirements still exist today. Cable assemblies made from this cordage are also known as jumpers, patchcords, pigtails, and interconnect cables.



Simplex
Single fiber cordage

Interconnect
Round configuration with two fibers.
Also known as dual-insulated buffer.

Duplex/Zipcord
Two round fiber cables lightly joined for easy separation.

Note: Breakout cables have numbers of the simplex versions built internally into the cable structure. These sub-units can vary from 1.6 mm to 3 mm.

TIA-598 Color Codes for Cordage

Jacket color	Fiber type	Description	IEC #
Yellow	Single-mode	ITU-T G.652, G.652D, G.655	OS1, OS2
Blue*	Single-mode	ITU-T G.657	—
Orange	Multimode	50/125 and 62.5 legacy	OM1, OM2
Aqua	Multimode	50/125 laser-optimized	OM3
Violet*, aqua	Multimode	50/125 laser-optimized	OM4
Lime	Multimode	50/125 laser-optimized	OM5

* Not standardized in the TIA-598 color code standard.

Indoor/Outdoor Cables

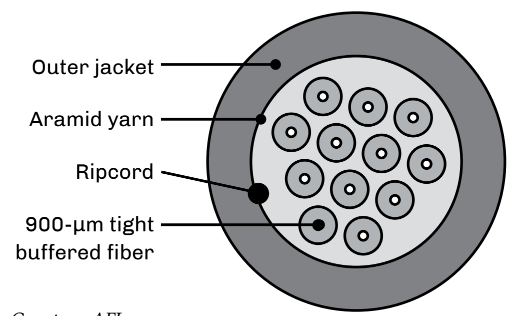
Indoor/outdoor cables are a cost-effective solution for applications that previously would have required a transition point at the building entrance to meet the 50-foot limitation required National Electric Code (NEC) for unlisted communications cables (NEC 770.48(A)).

To meet the requirements of the NEC, several considerations have to be designed into the cable structure. The cable cannot use jacket materials such as polyurethane (PU) or polyethylene (PE). The PVC jackets include a black UV stabilizer for higher UV resistance, required for aerial applications. The internal elements would have to meet the flame and toxicity requirements, eliminating most internal cable gels. The use of blocking tapes, aramid yarn, and special (nonhygroscopic, nonnutritive to fungus, nonconductive, homogenous, nontoxic) gels that meet the requirements of the NEC are key components that allow this cable to meet both the indoor and outdoor requirements.

ICEA S-104-696, TIA-472E000, or Telcordia GR-409

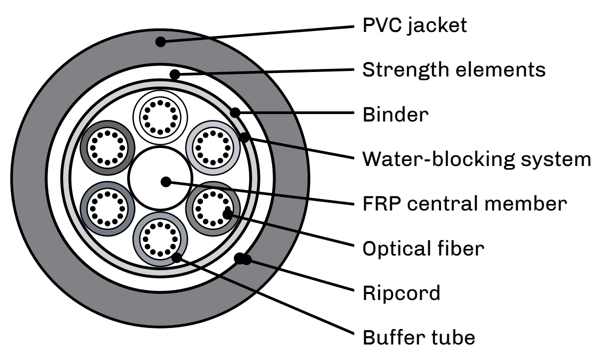
"Standard for Indoor/Outdoor Optical Fiber Cable"

- Features.
  - For installations in duct, direct buried, aerial, cable trays, riser, and plenums.
  - Available up to 288 fibers.
  - Heavy-duty versions.
  - Helically stranded.
  - OFNR, OFCR, OFNP, OFCP, and LSZH options.
- Benefits.
  - No transition point at entrance facilities required.
  - Faster to terminate.
  - Cleaner and easier to work with.
  - Fungus, water, and ultraviolet resistant.
  - Mid-entry techniques can be performed.
- Specifications.
  - Temperature: −40°C to 70°C.
  - Tension rating.
    - 600 pounds (more than 12 fibers).
    - 300 pounds (less than 12 fibers).
  - Bend radius.
    - 10x O.D. post-installation.
    - 20x O.D. during installation.



Courtesy AFL

Tight buffered distribution example
With sub-groups



Courtesy AFL

Loose buffered example

Loose Tube Outside Plant Cables

Cables used in outside plant applications must be designed to survive a large range of environmental conditions. The term outside plant (OSP) covers cables used in aerial, underground, and ducted applications. Issues for OSP cables include wind or ice loading effects, freezing conditions, or UV radiation from the sun. Damage caused by rodents, gun shots, or lightning, and instances of multiple cables being installed in the same duct (or innerduct) are also factors.

Of these, aerial cables require the most stringent specifications. This is due to thermal cycling from day to night and from season to season. Aerial cables must also handle the expansion and contraction stresses that these thermal cycles cause.

Aerial cables need to be attached to pole and tower structures to provide a firm grip onto the cable structure. Therefore, sag becomes an issue. The less the sag, the greater the tension on the cable clamps. The National Electrical Safety Code (NESC) also mandates clearances near highways, rivers, canals, and railroad tracks.

Over the years, a variety of cable structures have been developed for different installation methods for communication systems. Aerial, underground ducts, and direct buried cables are the basic three installation locations for optical cables. Once the location of the cable is known, then one must address the cable structure itself.

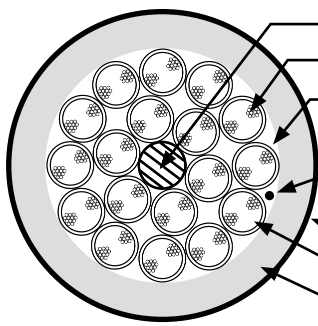
Installation type	Environmental conditions	Types of cable used
Aerial	• Thermal hot/cold cycling • Wind and ice loading • Lightning • UV from the sun • Expansion/contraction • Aging effects • Tension • Squirrels • Gunshots	• Optical ground wire (OPGW) • All-dielectric self-supporting (ADSS) • Outdoor cable (overlashed to messenger) • Figure 8 cable • Skywrap
Underground, ducted	• Possibility of water presence • Possibility of icing • Friction (for ducted installations) • Rodents • Dig-ups	• Stranded OSP cables • Unitube (central tube) OSP cables • Indoor/outdoor cables • Slotted core cables • Microduct cables

- Loose buffered.
- Stranded and unitube structures.
- 250-µm fiber coatings.
  - 200-µm fiber coatings for high fiber count cables.
- Designed for greater stress.
- Special designs for aerial, direct buried, duct and utility applications.
- Armored option.

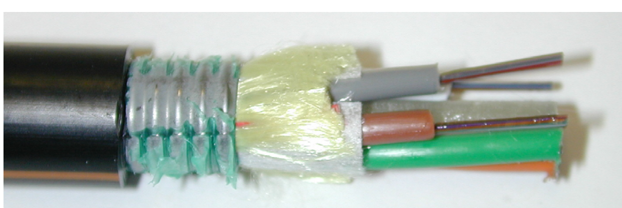
Stranded Cables

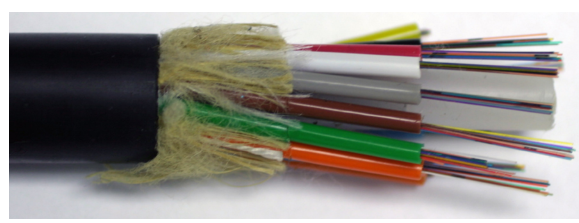
In stranded cables, individual color-coded buffer tubes are wrapped or stranded around the cable's central strength member, periodically reversing (reverse helical wrap or reverse oscillating lay). The tubes may be left dry or filled with gel to protect the fibers and can have one or two layers, depending on the fiber count required. Cables with fiber counts less than 288 fibers are generally stranded-type, while larger fiber counts are usually placed into a 12-fiber ribbon matrix.

Multistacking buffer tubes and grouping up to 24 fibers per tube has allowed for high fiber (432) counts. The drawback of this approach is that when OTDR testing, the inner tubes will show a shorter length versus the outer layer of tubes. This is due to the longer lay of the tubes during manufacturing. This should be noted on OTDR acceptance test forms.



Example of high fiber count loose tube stranded cable

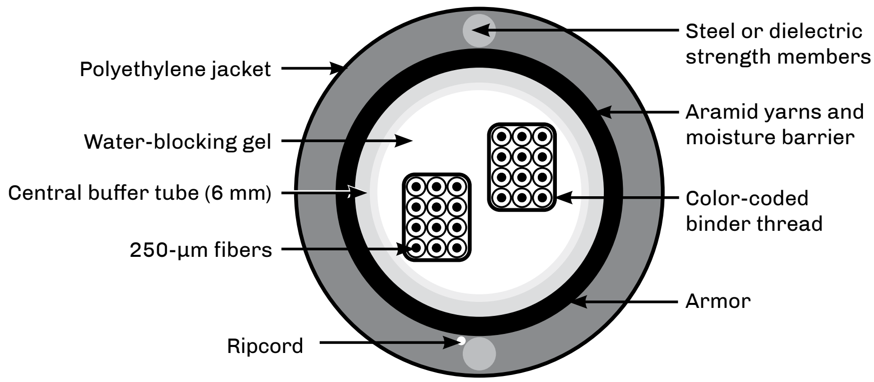




- A loose tube cable with individual color-coded buffer tubes are wrapped or stranded around the central strength member.
- Tubes may be dry or gel filled.
- Cables with 288 fibers or less are generally stranded-type, while larger fiber counts are usually ribbon-type.

Unitube Cables

Unitube cables are sometimes known as central tube or LXE cables. As opposed to stranded loose tube cables, these feature a large central tube in which fibers are grouped using a color-coded binder (yarn) per the TIA-598 color code standard. Cable structure can be physically smaller due to a central tube versus many multiple tubes around a central strength member. Cable has two steel or dielectric strength members 180° apart for cable strength and rigidity.



Notes: 1. Mid-entries require special tooling.

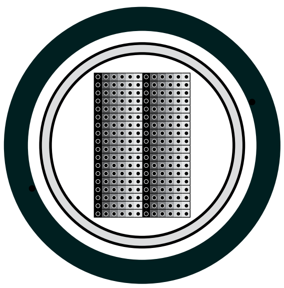
2. Fanout kits are unique for unitube/central tube cables.

3. If the cable is armored or has metallic strength members, it must be grounded per NEC Article 250 or NESC Section 9.

- Loose tube design.
- Also known as central tube or LXE cables.
- Use a large central tube with the fibers grouped using color-coded binder thread.
- Physically smaller than stranded types.
- FTTH drop cable design.
- Commonly used with internal ribbons.

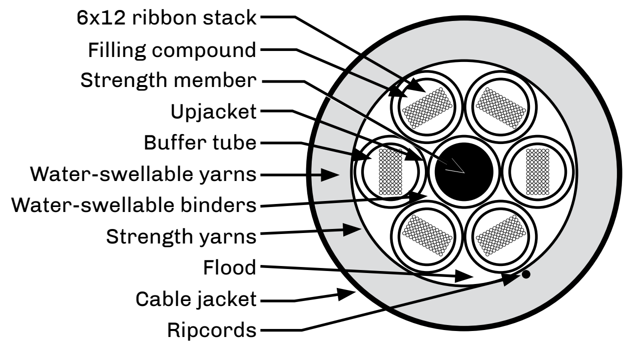
Ribbon Cables

High fiber count loose tube stranded ribbon cables are used in feeder and long haul routes. The use of ribbon fibers allows for high fiber counts. The stacking of six ribbons of twelve fibers each (or more) in each tube (six shown) allows for a fiber count of 432. Ribbon cables are also provided in counts of 864, 1152, 1,728 and 3,456. High fiber count cables are available with flat ribbons or with collapsible ribbon technology, allowing ribbons to be collapsed into a round shape then flattened into a standard ribbon format for easy splicing.

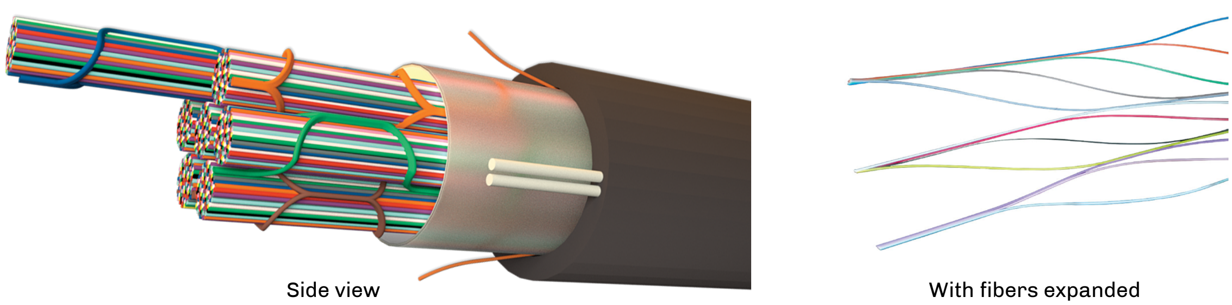


Unitube ribbon cable

Courtesy Corning Cable Systems



Fiber ribbons generally contain 8, 12 or 24 fibers, although the trend is to even higher fiber count ribbons with new banding and color markings for identification. Each fiber in the sequence is either individually color-coded or one fiber is colored and the rest are identified by their position in relationship to the reference fiber.



Spiderweb ribbon cable

- Used in feeder and long haul routes.
- Available in counts from 432 fibers to 3,456 fibers.
- Fiber ribbons contain two or more fibers.
- Each fiber is individually color coded, or one fiber is color-coded and the rest are identified in relation to the reference fiber.

Microduct Cables

Microduct cables are a small diameter cable with high density fiber counts up to 432 fibers. This provides efficient utilization of duct space and reduces installation costs when used with cable jetting technology and microducts with diameters ranging from 5 mm to 16 mm.

Compliant with Telcordia GR-20 and IEC 60794 standards, it is available as an outdoor cable with HDPE jacketing, or as an indoor PVC riser or LSZH cable, or as an indoor/outdoor design. The outdoor design is a dielectric design with water blocking and intrinsic ripcord.

Fiber options include single-mode and multimode types in stranded or central tube designs.

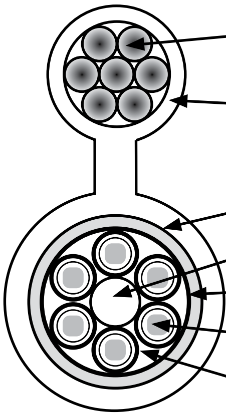
Mechanical Specifications		
Bend radius	Dynamic	20X – 40X
	Static	15X – 20X
Tension	Installation	300 lbs (1335 Newtons)
	Static	90 lbs (400 Newtons)
Outside diameter		0.25” - 0.85”

- Small diameter cables with high density fiber counts.
  - Two to 432 fibers.
- Efficient utilization of duct space.
- Reduced installation costs when used with cable jetting.
- Meets Telcordia GR-20 requirements.
- Indoor or outdoor.
- Single-mode or multimode.
- Stranded or central tube.

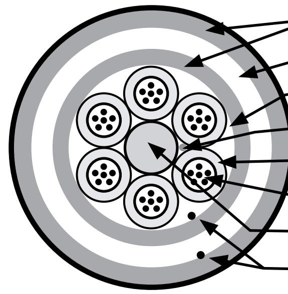
Aerial Fiber Optic Cables

Aerial cables must be specifically designed to handle the environment over their life span. Wind and ice loading, pollution, UV radiation, thermal cycling, stress, and aging are a few considerations that must be addressed when selecting aerial cable. Several styles are available, varying based on intended placement, application, and environment.

Figure 8



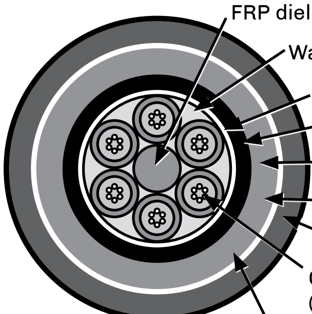
Loose Tube Overlashed To Messenger



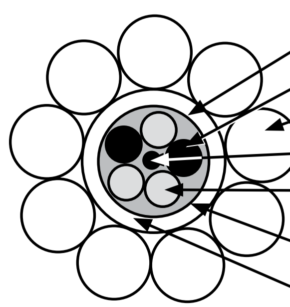
Typical ADSS Specifications

Specified span length (ft.) Nominal sag (ft.) Nominal axial load (lbs.)	600 6 (1%) 750	800 8 (1%) 1,635	1,250 12.5 (1%) 2,070	1,500 22.5 (1.5%) 2,350
Number of fibers Cable diameter (in.) Cable weight (lbs./mi.) Minimum bend radius (in.) Cable breaking strength (lbs.)	12 0.53 525 10 7,500	22 0.68 865 13 9,500	16 0.61 700 12 13,400	48 0.73 995 14 19,000
NESC heavy condition Sag (%) Axial load (lbs.)	 3.5 2,100	 3.5 3,400	 3.5 4,800	 3.5 6,000

All-dielectric Self-supporting (ADSS)



Optical Ground Wire (OPGW) Utility Static Wire



ADSS Fiber Cables

IEEE P-1222

Mostly used by utilities, all-dielectric self-supporting (ADSS) fiber optic cable cable can be installed as an underbuild on existing electric lines without de-energizing the electric circuit.

All ADSS cables have a central core of dielectric fiberglass reinforced plastic (FRP) anti-buckling element. Spaced around the anti-buckling element are variable quantities of gel-filled loose tubes that contain the optical fibers, followed by water blocking binders. Around all these items is the non hygroscopic core wrap. Some ADSS cables also have a polyethylene inner jacket.

The following layer contains the cable's strength member — the aramid yarns — which are torsionally balanced to prevent twisting during installation. Next comes a nonhygroscopic core wrap. The polyethylene outer jacket varies in thickness. When the cable is to be installed adjacent to or as an underbuild on an extremely high voltage (EHV) electric line, their outer jacket is a cross-linked polymer with anti-tracking additives.

Big ADSS cables require a lot of Kevlar™ for strength; this is applied by wrapping Kevlar yarns helically around the core of the cable. When a lot of Kevlar is required, the Kevlar is wrapped in several counter-rotating layers. This gives a torsionally-balanced design in which the tendency for the cable to rotate from one layer of Kevlar is cancelled out by the next layer. The different layers are at different distances out from the core and therefore have different torsional effects. The core itself is also helical and contributes to the total torsion in the cable. So it is very difficult to get a fully torsionally-balanced design.

Comparison of ADSS Cable Design Examples

	Long span	Medium span	Short span
Fiber count	2 - 576	2 - 432	2 - 288
Diameter	0.535 - 1.142 in 13.6 - 29 mm	0.512 - 0.969 in 13 - 24.6 mm	0.323 - 0.693 in 8.2 - 17.6 mm
Rating breaking strength	6,100 - 16,400 lbs 2,766 - 7,439 kg	3,100 - 8,080 lbs 1,406 - 3,665 kg	2,625 - 4,250 lbs 1,191 - 1,927 kg
Span length	800 - 2,100 feet 274 - 640 meters	100 - 1000 feet 30.5 - 305 meters	50 - 900 feet 15.25 - 274 meters

Each has a certain number of fibers, certain dimensional data and a certain rated breaking strength (RBS), or maximum rated cable load (MRCL), and is utilized under varying conditions in the field.

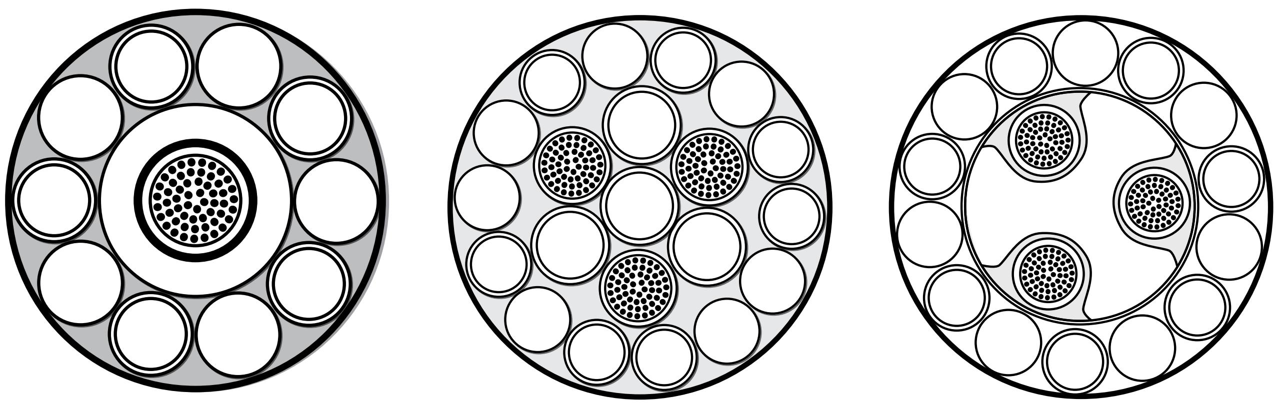
ADSS fiber optic cable is being designed and manufactured in accordance with IEEE P-1222, the worldwide standard for ADSS cable.

Optical Ground Wire Cables

IEEE 1138

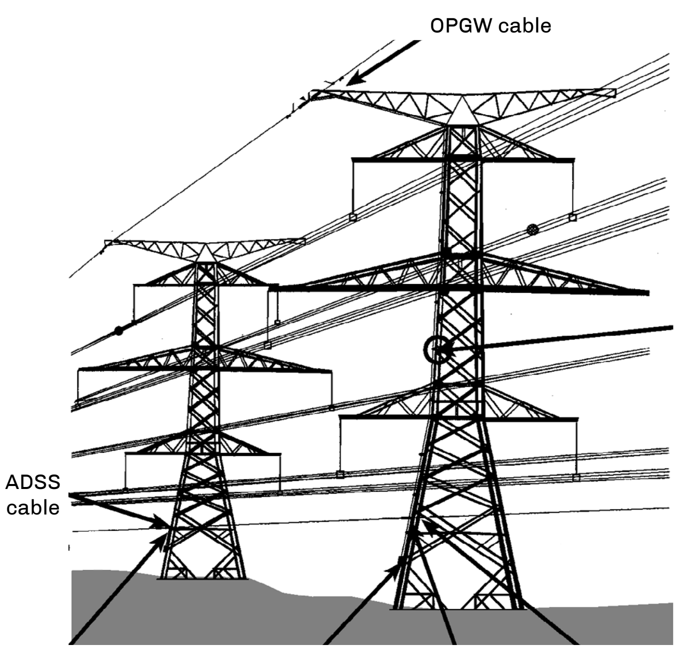
Optical ground wire (OPGW) cable is manufactured from a minimum of four fibers up to a maximum of 432 fibers. Research is underway to assemble an OPGW cable with greater than 432 fibers. Reels of OPGW can be manufactured in lengths up to 6,000 meters (19,685 feet). On most projects these lengths vary according to the distance between the splice points. Longer lengths can be manufactured at an increased cost.

Optical fibers are placed in hermetically-sealed stainless steel or aluminum tubes. They are also placed in grooves on an aluminum channel core. Around the tubes or channel core is wound aluminum alloy and aluminum-clad steel strands. The number of each strand applied depends on the required fault current capacity and rated breaking strength (RBS) of the cable. The strands can be a combination of the two wire types and installed as a single layer of wrap. If a higher fault current capacity or RBS is required, two layers can be installed. The inner layer is the aluminum-clad steel strands for cable strength. The outer layer is aluminum alloy strands for fault current. There are designs where the two are interwoven. Each requirement warrants a special investigation as to the design characteristics of the fiber optic cable.



Unitube HexaCore Channel Core

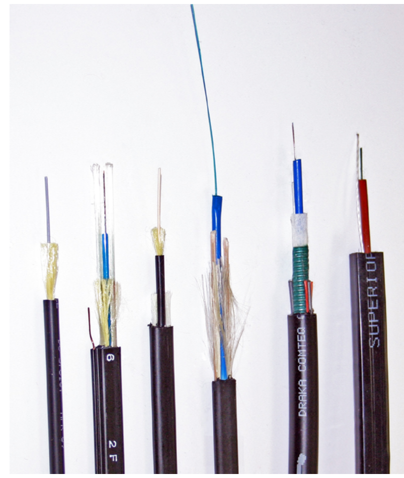
Courtesy AFL



OPGW is installed on the top of electric power line structures where it is used to carry the fiber optic glass as well as to shield the power line against lightning strikes.

FTTx Drop Cables

FTTx drop cables provide the final delivery to the subscriber. Traditionally, drop cables have had low fiber counts from 1 to 12 fibers. Many were flat cable designs, taking fiber to the subscriber location. With various FTTx applications dropping fiber to single homes and multiple dwelling units, drop cables now come in higher fiber counts and in flat, round, and even armored designs.



Customer drop cables can be an aerial or an underground installation. Underground drop cables include a metallic strand for locating. The individual customer requirements for the drop cable to the building determines which of the varied styles will be used. Because of the short spans that are involved with drop cables, they are designed for lower tensile strengths (typically 300 lbs.) and have lower fiber counts, i.e., one to two fibers for FTTH and up to twelve fibers for FTTB.

Sample Specifications for Smaller Drop Cables

Fiber count	Nominal diameter mm (in)	Nominal weight kg/km (lbs/kft)	Max tensile loading		Min. tensile loading	
			Install n (lbs)	Long term n (lbs)	Install mm (in)	Long term mm (in)
2 – 12	7.0 (0.28)	44 (30)	1335 (300)	445 (100)	140 (5.5)	70 (2.8)

Environmental Temperature Specifications

- Operation/storage — −50℃ to +70℃
- Installation — −30℃ to +75℃

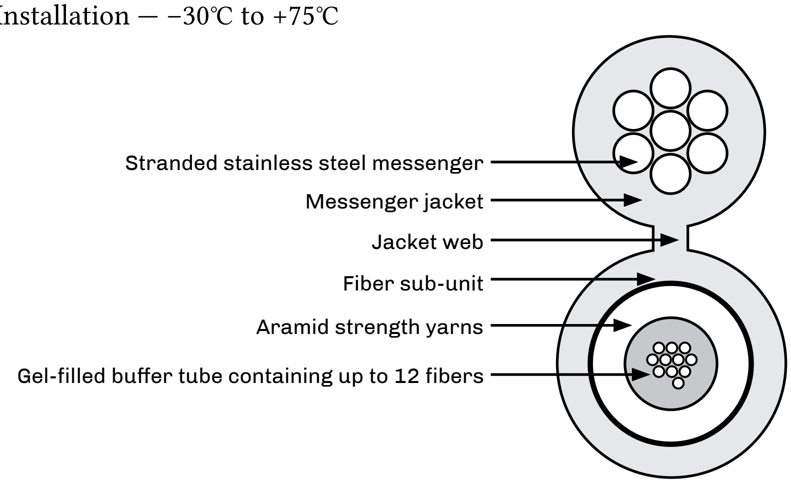


Figure 8 style drop cable

Courtesy Prysmian

- Aerial, direct buried, and ducted versions.
- 300-pound tension rating.
- Unitube structure.
- Optional tracer wire.
- Fiber counts from 2-12.

Questions to Ask
When Evaluating the Right Cable Design

1. Does the cable meet the environmental requirements?
2. Does the cable meet the applicable building codes?
3. Does the cable have the correct cable jacket for the application?
4. Does the cable meet the mechanical specifications? (Check tension, bend radius, diameter.)
5. Does the cable require armoring?
6. Should the cable be a dielectric design?
7. Are the fibers and buffer tubes color coded? Are these standard to TIA-598 and/or IEC 60304?
8. For loose tube cables, what are the fiber per tube counts and designations?
9. Does the cable have sequential markings? Are these in metric or in footage?
10. Does the cable include ripcords to assist in cable preparation?
11. Are there shipping tolerances to consider? Most cables are shipped with ±5% tolerances, with the invoice amount being actual cable length.
12. Have you considered shipping reels, identification, and documentation issues?

Typical Optical Cable Specifications

General Purpose Loose Tube Outdoor Cable

Parameter		Units	Specifications					
Jacket (PE)			Single		Double		Triple	
Armor			None		Single		Double	
Central strength member			Steel	Dielectric	Steel	Dielectric	Steel	Dielectric
Fiber count			4-144	4-144	4-144	4-144	4-144	4-144
Cable outside diameter		mm	12-19	12.5-19.3	15.3-22.3	15.8-22.6	19.4-26.4	19.4-26.4
Cable weight		kg/km	165-335	130-300	290-535	255-500	485-795	455-760
Bend radius	Dynamic	X Cable O.D.	20		20		20	
	Static	X Cable O.D.	10		10		10	
Storage temperature		°C	−50 to +70		−50 to +70		−50 to +70	
Operating temperature		°C	−40 to 65		−40 to +65		−50 to +65	
Tensile rating	Installation	N (lbs.)	2700 (600)		2700 (600)		2700 (600)	
	Static	N (lbs.)	500 (110)		500 (110)		500 (110)	

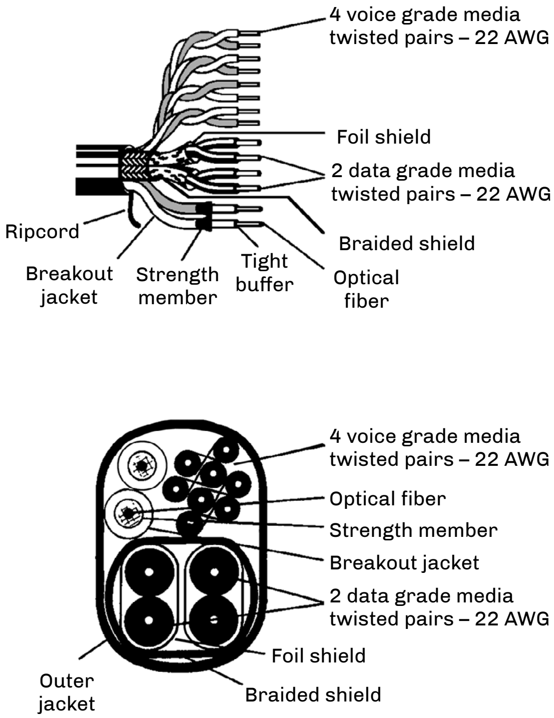
Fiber and Buffer Color Codes

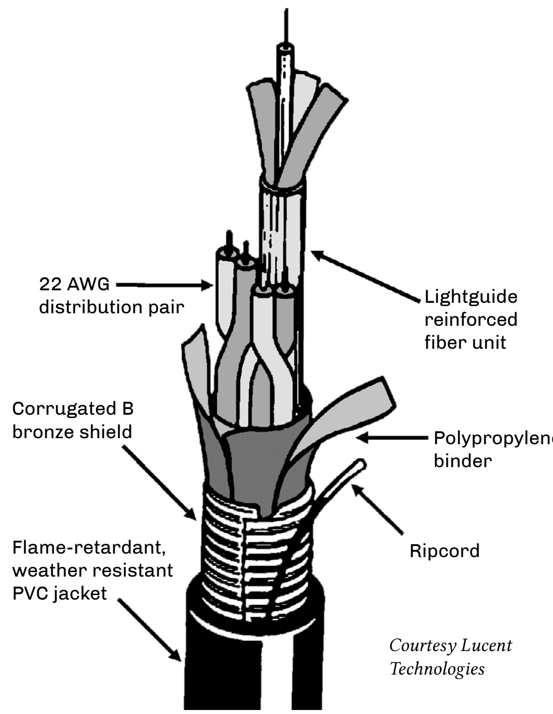
The colors and designations in TIA-598 are also used for the buffer tubes and twines in loose tube outside plant cables, as well as in the fibers and subgroups in indoor distribution and breakout tight buffered cables.

Based on 12 colors per fiber grouping (e.g., tube or bundle), the 13th fiber in a cable would be connected to port 13 in a patch panel. It would be the first (blue) fiber in the second (orange) tube.

		Tube Color											
		Blue	Orange	Green	Brown	Slate	White	Red	Black	Yellow	Violet	Rose	Aqua
Fiber Color	Blue	1	13	25	37	49	61	73	85	97	109	121	133
	Orange	2	14	26	38	50	62	74	86	98	110	122	134
	Green	3	15	27	39	51	63	75	87	99	111	123	135
	Brown	4	16	28	40	52	64	76	88	100	112	124	136
	Slate	5	17	29	41	53	65	77	89	101	113	125	137
	White	6	18	30	42	54	66	78	90	102	114	126	138
	Red	7	19	31	43	55	67	79	91	103	115	127	139
	Black	8	20	32	44	56	68	80	92	104	116	128	140
	Yellow	9	21	33	45	57	69	81	93	105	117	129	141
	Violet	10	22	34	46	58	70	82	94	106	118	130	142
	Rose	11	23	35	47	59	71	83	95	107	119	131	143
	Aqua	12	24	36	48	60	72	84	96	108	120	132	144

Composite and Hybrid Cables





Indoor (left) and outdoor (right) composite cable

Composite Cable

A unique type of cable designed for multipurpose applications. Both optical fibers, and twisted pair wires and/or coax are jacketed together for situations where both technologies are presently used.

The NEC defines composite cable as containing both optical fibers and current-carrying electrical conductors in the same jacket.

An additional usage of this cable style is when future expansion for optical fibers is being planned. This cable allows for existing copper networks to be upgraded to fiber without requiring new cable to be installed. This can be accomplished without disrupting the existing service.

In application areas such as local area networks and fiber to the curb, a smooth transition can be made from copper to fiber. The addition of the copper can also resolve the powering issues of remote electronics such as in the HDTV camera cable.

Hybrid Cables

Designs are available with multiple elements including specific fiber types (multimode or single-mode). These fibers are color coded for easy identification. As with other conventional types of cables, the hybrid types can be manufactured to best meet the user’s environmental and transmission requirements.

Note: Be careful of the terms hybrid and composite. There is no uniformity in the descriptions as defined by TIA-440-B Fiber Optic Glossary Standard.

Cable Interconnection Options

Distribution Cables

- **Multimode:**
  a. Connectors directly terminated onto 900-µm buffer coating.
  b. Pigtail spliced (mechanical or fusion); requires a splice tray.
  c. Mechanical splice-on connectors.
  d. Fuse-on connectors.
- **Single-mode:**
  a. Pigtail spliced (mechanical or fusion); requires a splice tray.
  b. Mechanical splice-on connectors.
  c. Fuse-on connectors..

Breakout Cables

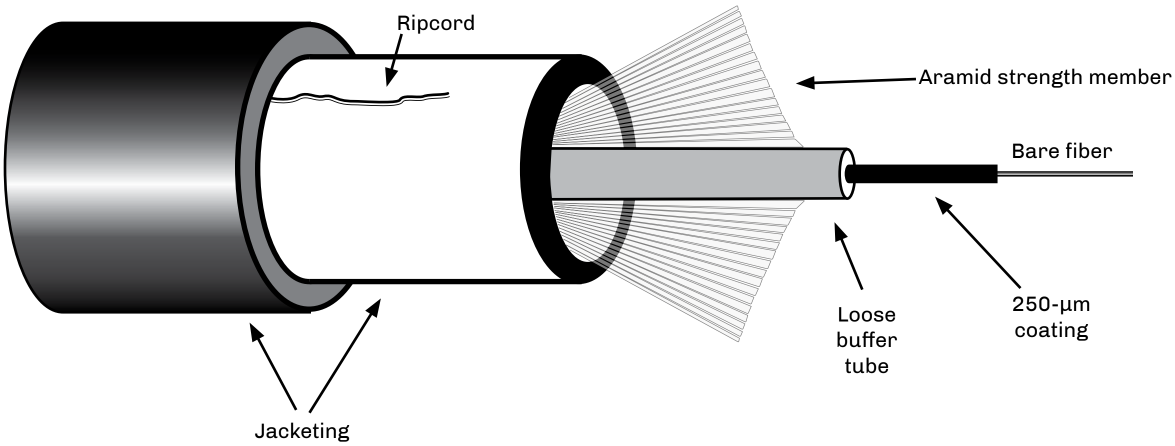
- **Multimode:**
  a. Connectors directly terminated onto 1.6, 2.0, or 3.0-mm sub-unit.
  b. Pigtail spliced.
  c. Direct connectorization using splice-on plugs.
- **Single-mode:**
  a. Pigtail spliced (mechanical or fusion); requires a splice tray.
  b. Fuse Connect connectors.
  c. Direct connectorization using splice-on plugs with prepolished UPC and APC endfaces.

Loose Tube Outdoor Cables – 250-µm Coating (Central Tube or Stranded)

- **Multimode:**
  a. Fanout kit to build 250-µm coating up to 900 µm.
  b. Direct termination onto fanout kit (900 µm).
  c. Pigtail spliced (mechanical or fusion); requires a splice tray.
  d. Direct connectorization using splice-on connectors.
- **Single-mode:**
  a. Pigtail spliced (mechanical or fusion); requires a splice tray.
  b. Fuse-on connectors.
  c. Fanout kit to build 250-µm coating up to 900 µm.
  d. Direct connectorization using splice-on plugs with prepolished UPC and APC endfaces.

Loose Tube Cable Preparation

For Splicing and Connectorization



To prepare a fiber for splicing or connectorization, the cable's protective outer jacket(s), armoring*, and buffer tubes must be removed to allow access to the individual optical fibers. In this drawing, the cable's outer and inner jackets and buffer tube are removed to expose the aramid strength member and internal fibers. The fiber still has the protective coating, which will also have to be removed prior to splicing or connectorization.

To remove the outer jackets, standard cable strippers can be used. Make sure the blades or cutting members do not damage the internal buffer tubes. First cut a small section (6") of the cable's jacket to allow access to the ripcord, make tool adjustments, and practice a few cuts. When using a ripcord for access, a small notch is made in the outer cable jacket to allow the ripcord to start (without breaking). A small length of ripcord should be left for future access to the cable.

The aramid strength members now can be removed with splicer's scissors or aramid cutters. The amount of aramid yarn removed varies depending upon the design of the cable's strength member. If the cable does not incorporate a strength member, the aramid yarn can be used as one.

The buffer tubes, like the outer jacket, can be removed by mechanical stripping tools. The operator should be careful not to kink or damage the internal coated fibers.

Once the coated fibers are exposed, the splicer must remove the fiber's 250-µm protective coating before cleaving can begin. Most coatings can be stripped using mechanical methods. The splicer should take care to use tools and procedures that will not damage the fibers.

After the fiber's coating is removed, clean the fiber with isopropyl alcohol to ensure that it is clean. Contaminants on the fibers can cause it to misalign in the splicer's alignment fixture and contaminate the splicer's V-grooves.

* The armoring, not shown in the graphic, would be between the inner and outer jackets.

Chapter 4 Review

1. What colors are used for single-mode cordage? What about for multimode cordage?

2. What is the outside coating diameter of the fiber used in tight buffered cables?

3. What is the outside coating diameter of the fiber in loose buffered cables?

4. What are the names of the two types of indoor tight buffered cables?

5. What is a composite cable?

6. What does the acronym OFNR signify?

7. What do gels, tapes, and powders in fibers protect against?

8. If a cable has any metallic components at termination point, what does the NEC require?

9. What is the NEC 50 foot rule?

10. Sequential markings on the outside of cable jackets help to approximate what?

Chapter 4 Review

11. What must installers consider when installing fiber optic cables?

12. What is the dynamic bend radius for fiber optic cable?

13. What type of cable do central tube and stranded refer to?

14. What is the maximum pull tension for traditional outside plant cables?

15. What type of damage was armored cable designed to prevent?

Student Notes

Chapter 5

Connectors

By the end of this chapter, you will be able to:

- List the main components of a fiber optic connector
- Name the connector types most commonly used in optical networks
- Discuss the basic types of connector polishes
- State reasons why cleaning optical connectors is important

Fiber Optic Connectors

Connectors offer a mechanical means to terminate optical fibers to other fibers and to active devices, which connect transmitters, receivers, and cables into working links.

The primary task of the fiber optic connector is to minimize the optical loss across the interface of the coupled fibers. High-performance connectors are classified as those with less than 0.75 dB of loss for premise applications and 0.5 dB for high-speed single-mode applications. Most losses occur from inexact end-to-end mating of the fibers, the surface condition of fiber ends, and fiber and ferrule tolerances.

The second task of the connector is to provide mechanical and environmental protection and stability to the mated junction.

The third task is to minimize reflections by maintaining physical contact, which reduce Fresnel reflections between fiber surfaces. An ideal connector would encompass the following features:

- Utilize a fiber alignment scheme yielding low loss;
- Be physically small;
- Have low reflectance values;
- Be of rugged construction;
- Be easily field terminated;*
- Offer excellent fiber/cable strain relief; and
- Have good repeatability.

To minimize the attenuation of a connection, certain conditions must be met. First, the fiber ends must be optically flat (multimode), spherically polished or angled, and smooth. Second, the alignment of both fibers must be precise.

With high-speed digital systems and analog video systems that incorporate laser sources using single-mode fiber, the connectorized fiber endface can become a highly-reflective surface. To prevent Fresnel reflections from interfering with system performance, several types of optical finishing techniques have been developed. Called physical contact (PC) endfaces, the fibers can be polished at angles (APC) or spherically (UPC/SPC) to minimize Fresnel reflections.

Fiber optic connectors are specified by the TIA 604 Fiber Optic Connector Repeatability Intermateability Standard (FOCIS) in North America, and the IEC 61753/61754 for international use. The FOCIS 604 specifications define the minimum physical attributes of mating fiber optic connector components. The specification includes types, configurations, tolerances, keys, polishes, and, in many cases, connector terminology.

Connector Keys

Since the early 1980s, the dominant fiber optic connectors have provided male keys and female keyways to assist with the alignment of the fibers, ferrules, and plugs. Keyed connectors allow for 0.2 dB repeatability of optical measurements. In the case of APC connectors, keying is essential to proper alignment, as specified by Telcordia GR-326.

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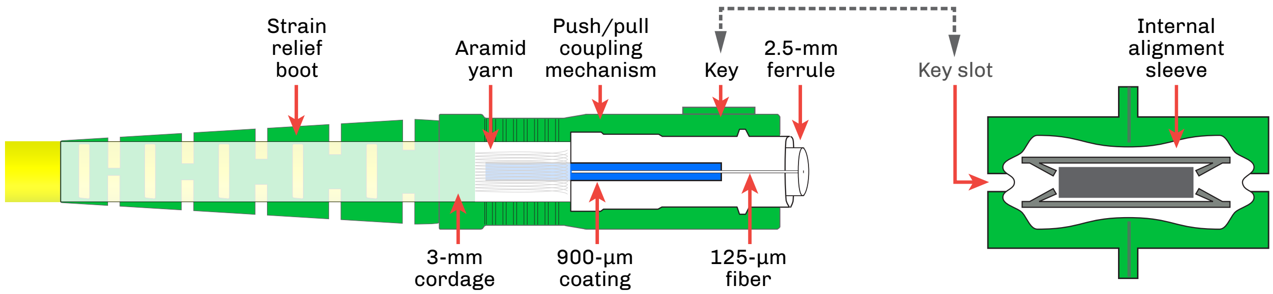
* Factory-terminated cable assemblies provide the option to field connectorize using no-polish connectors or to splice pigtail assemblies using fusion or mechanical splices. This is critical with single-mode fibers due to reflection problems with hand-polished connectors. Cleave and crimp connectors with prepolished fiber stubs, using a precision cleaving tool, allow direct connectorization to single-mode cables.

Main Connector Components



SC connector plug, side view

SC adapter, top view

- **Boot:** Designed to provide strain relief at the connector/cable interface.
- **Body:** Also called the housing, this typically plastic or metal part provides the mechanical attachment to the sleeve using push/pull (SC and LC), threaded (FC), or bayonet (ST) coupling mechanisms.
- **Ferrule:** The precision part of an optical plug that provides the fiber optic centering and stabilizing of the fiber. The optical fiber's cladding is retained in the ferrule either by adhesive or crimp techniques. Usually consists of a hardened material such as ceramic (zirconia), stainless steel, and tungsten carbide. Typical ferrule diameters are 2.5 mm for standard (ST, SC, FC) plugs and 1.25 mm for small form factor (LC) plugs.
- **Alignment sleeve:** Internal to all adapters, a precision internal mechanism is required to axially align the mating ferrule(s). A ceramic C-clip is the most commonly used method. The C-clip slot is compressed and inserted into the sleeve. Once released, it will expand and lock itself into the adapter sleeve. Sleeves can also be of solid design and sometimes come in metallic versions.
- **Adapter:** Also known as a bulkhead, the adapter is for mechanical mating of the mating plugs and its internal C-clip aligns the optical ferrules. Adapters used in patch panels allow interconnections to be made between transmission equipment and fiber spans. Never use the term coupler (also known as a splitter) to describe a sleeve; in fiber optics, a coupler splits optical signals.

Causes of Excess Loss

Connector

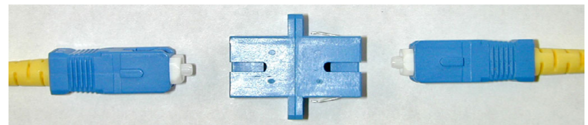
- Axial separation
- Angular misalignment
- Radial displacement
- Endface damage
- Contamination and dirt

Fiber

- Core mismatch
- Numerical aperture
- Core/cladding concentricity
- Cladding ovality

Connector Types

1. **In-line style.**
   Consists of two plugs with a middle adapter. Sleeves are used to mechanically align the two mating ferrules. Loss across the entire connection should be 0.75 dB or less for multimode fiber and 0.5 dB for single-mode. Sometimes called housings or bulkheads.



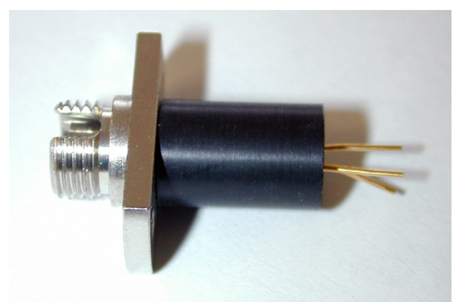
In-line connector assembly

2. **Multifiber.**
   Consists of a plug and mating receptacle with male and female termini (pins and sockets). This approach offers multiple fiber interfaces and most are easy to connect or disconnect. However, the disadvantages are higher costs, optical repeatability, and difficulty to repair. Types include broadcast, military, and array connectors such as MPO/MTP.

Multifiber broadcast connector

Courtesy LEMO

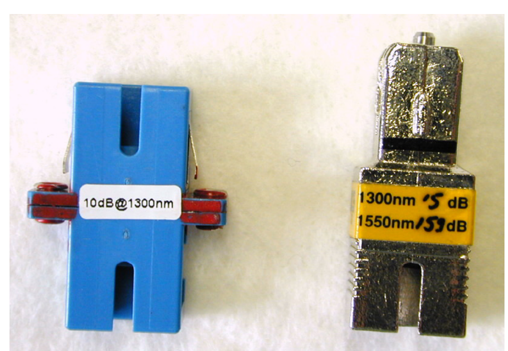
3. **Receptacle for active devices.**
   Consists of a receptacle housing built to align the plug with the window of a LED, laser, photodetector, or photodiode.



Active decive receptacle

4. **Attenuators.**
   Attenuators consist of adapters with an internal filter that attenuates the optical signal at specific wavelengths. A wide variety of constructions are available providing fixed or variable amounts of attenuation. Attenuators can be reflective or nonreflective, and provided with or without connectors, e.g., in-line patchcords.

5. **Terminators.**
   Terminators are modified plugs with the same endface polish as the network connection. They are used in high optical power systems to reduce Fresnel reflections.



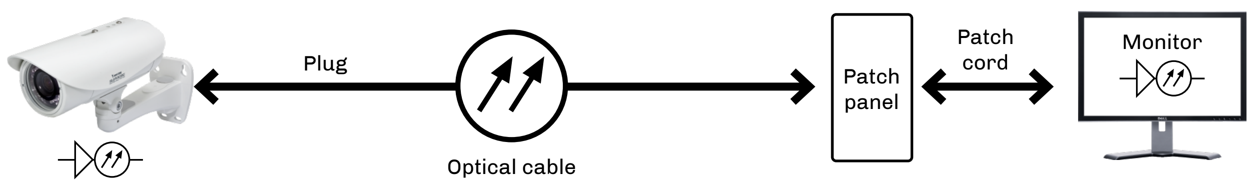
Attenuators

What to Look for in a Connector

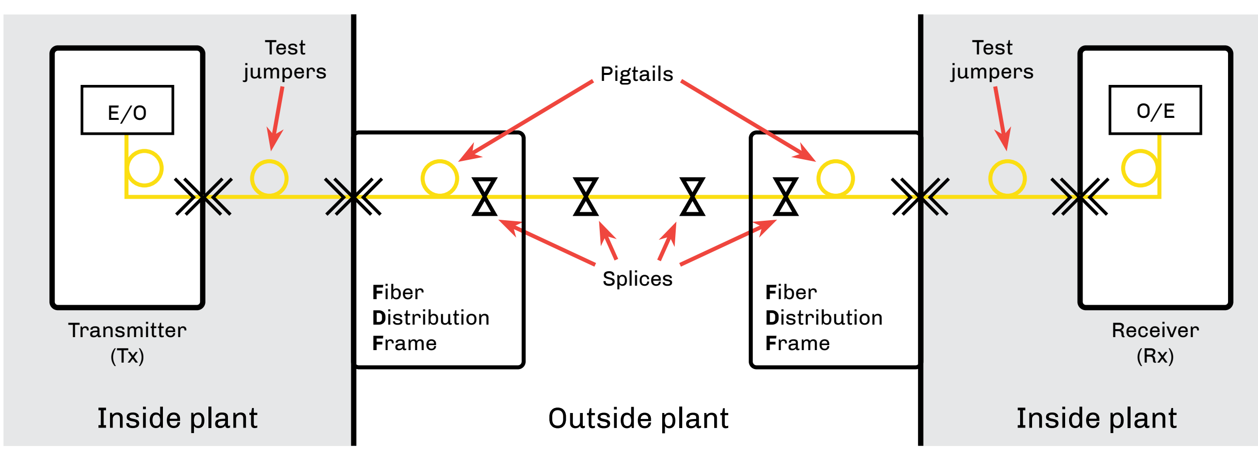
- Low loss (attenuation)
  - 0.50 dB – ITU-T G.671.
  - 0.75 dB – TIA-568.
  - 0.40 dB – Telcordia GR-326-CORE.
- Repeatability (keyed)
  - 0.2 dB – Telcordia GR-326-CORE.
- Reflectivity (in dB)
  - >20 dB (62.5/125 fiber) – IEEE 802.3, TIA-568
  - >35 dB (single-mode fiber) – TIA-568
  - >55 dB (CATV) – TIA-568
  - >50 dB (UPC polish)
  - >65 dB (APC polish)
- Rugged (strain relief).

Typical Connector Roles

Point-to-point CCTV

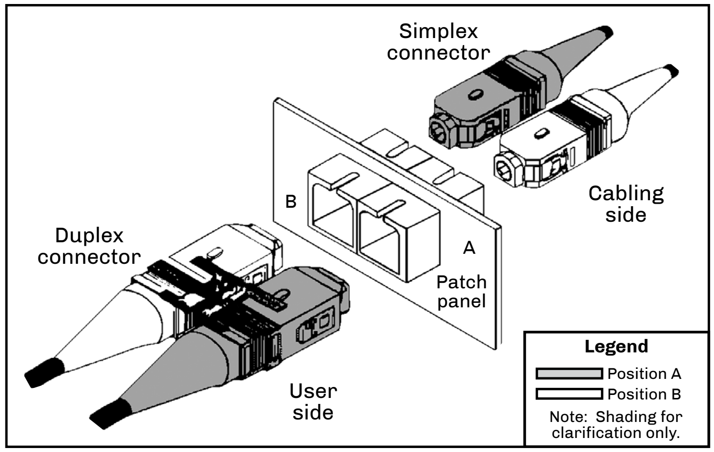


Network Example



Subscriber Connector (SC)

Standardized in TIA-604 (FOCIS-3) and IEC 61754-4, SC connectors have a 2.5-mm ferrule and are keyed to prevent cross-mating. They use a push/pull design to mate and unmate, and are available in simplex or duplex styles (SCFOC2.5).

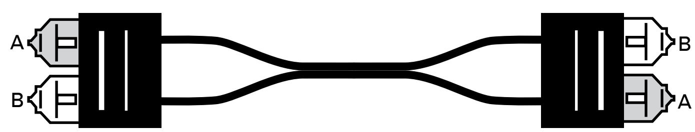


SC connectors are color coded based on fiber and polish type:

- Beige for multimode
- Green for single-mode with APC polish
- Blue for single-mode with PC, SPC, or UPC polish

SC hybrid adapters are available for easy migration to networks wired for LC, FC, or ST connectors.

- Standardized by TIA-604 (FOCIS-3) and IEC 61754-4.
- 2.5 mm ferrules.
- Keyed push/pull design.
- Simplex or duplex.
- Color coded.

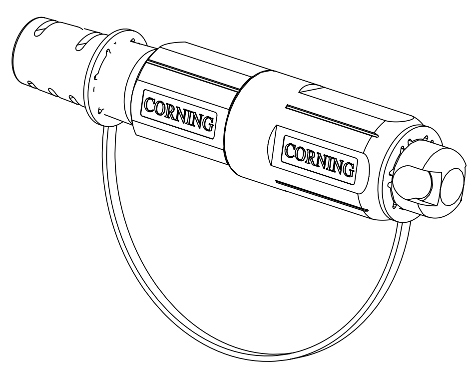


Duplex SC optical fiber patch cord

Hardened SC Connectors

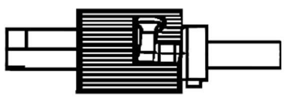
This version of the SC connector is specified by Telcordia GR-3120 requirements. It is keyed with a threaded coupling housing. The hybrid adapter allows it to be coupled with standard SC/APC or SC/UPC pigtails, while the mating plug is environmentally-sealed for OSP and FTTx applications. This connector is terminated onto factory-built drop cables for quick installations to outside plant cable management products and FTTx termination points.

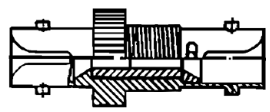
- Specified by Telcordia GR-3120.
- Environmentally sealed for OSP and FTTx applications.
- Quick termination to factory-built drop cables.



BFOC/2.5 (ST)

The de facto standard multimode connector of the late 1980s and early 1990s, the bayonet fiber-optic connector (BFOC) style standardized in the IEC 61754-2 and TIA-604-2 standards. Available in ST and STII versions, the style is keyed, has a 2.5-mm ferrule, and uses a push/turn (bayonet) motion to attach to its mating sleeve (adapter). It is used in single-mode and multimode applications, but has the most use in multimode LANs and CCTV security systems.


ST plug


ST sleeve

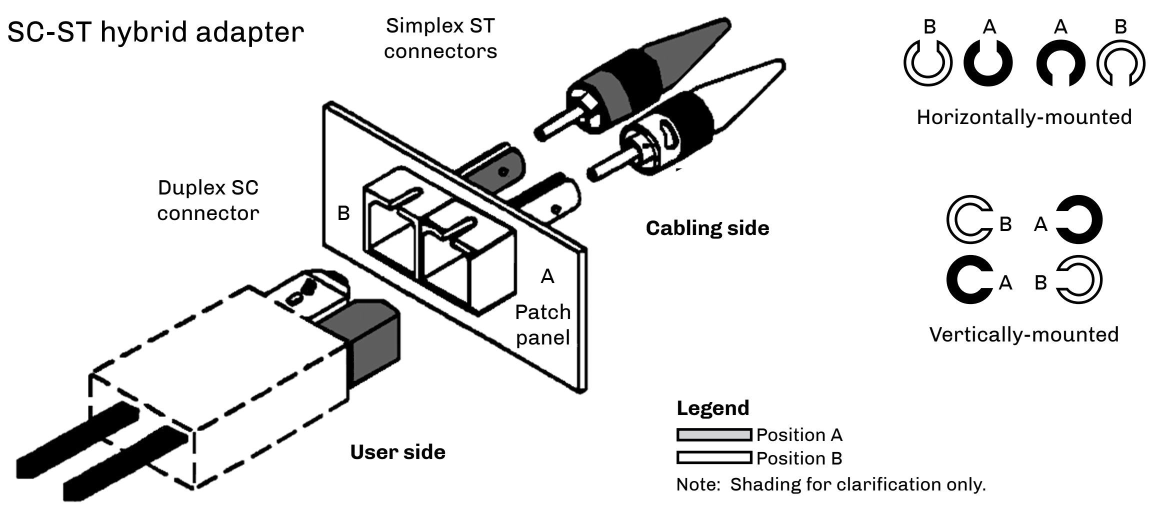

ST II plug

As most standards now use the push/pull SC and LC connectors, use of the ST is declining, but it is still used in CCTV and industrial control applications. Hybrid solutions, whether they be jumpers or adapters, provide current users and manufacturers of network equipment with a migration path from ST connectors to SC and LC connectors.

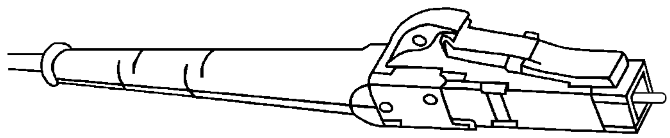
ST and STII Connectors

Two types of ST connectors are manufactured: ST and STII. The stock ST style utilizes an open-ended bayonet slot design for the knurled, retaining lock. The STII style adds an enclosing ring around the rim of the bayonet slot. This strengthens the slot area, reducing deformation from over-tightening. Both types are intermateable with one another.

- ST and STII.
- Specified by IEC 61754-2 and TIA-604-2.
- Multimode and single-mode versions.
- Standard 2.5 mm ferrule.
- De facto standard of late 1980s and early 1990s.



LC Connector



The LC connector was the first successful small form factor (SFF) connector. Its latched design provides confirmed engagement with the click of the latch, while the 1.25-mm ferrule helps with its reduced size for added density. This connector can be UPC or APC polished and is available in as simplex or in a duplex configuration that occupies the same footprint as a single SC-type connector.

Because of its small size, the increase in density for component board assemblies, interconnect panels, network closets and outlets is increased by 100%. Due to their small size, the LC connector is standardized on most small form factor pluggable (SFP), SFP+, and 10 Gigabit small form factor pluggable (XFP) transmission equipment.

Specified by the IEC 61754-20, TIA 604-10 FOCIS, and TIA-942 standards, the all-in-one connector body equals the side-load requirements of the standard 2.5-mm connectors and also meets TIA-568 and ISO/IEC 11801 performance specifications.

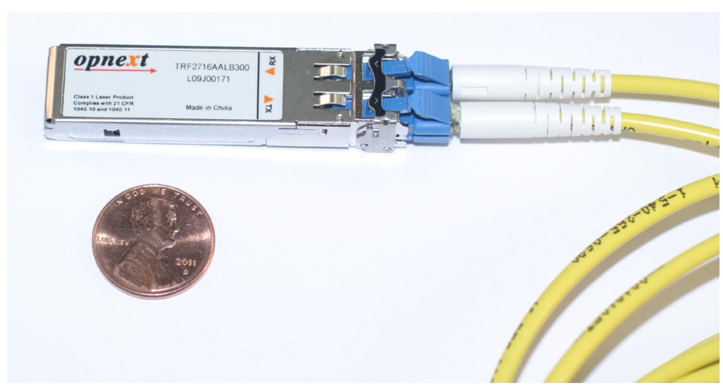
The connector latch mechanism has been designed similarly to the RJ-style telephone plug, assuring proper keying and positive locking of the connector into the receptacle. Some LC connectors have been manufactured with a field-installable, extended duplex latch clip. This helps to eliminate:

- Polarity issues in duplex cable assemblies with connector pairs that remain separated.
- Mislatching one connector or the other in the duplex receptacle.

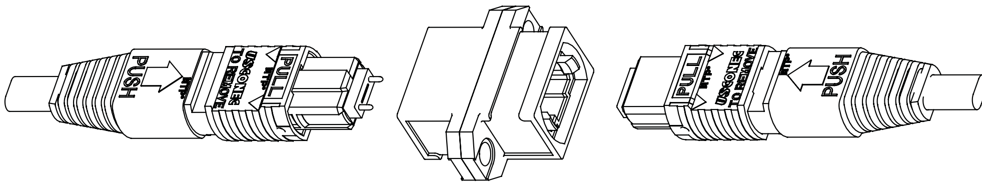
LC connectors are most often used with 900-micron, 1.6-mm or 2.0-mm cordage, but are available with boot options to accommodate many different cable designs.

Features

- Small size.
- High density.
- Single-mode or multimode versions.
- Low attenuation.
- Low reflectance.
- Commonly used on transmission products.



Multifiber Push-on Connectors



Courtesy USConec

Multifiber coupling

The multifiber push-on (MPO) connector and mechanical transferable (MT) ferrule technology were developed by NTT Labs in the early 1980s. Also known as an array connector, the MPO is standardized by IEC 61754-7 and TIA-604 FOCIS-5 for both multimode and single-mode applications. The connector housings are color coded for the type of fiber used in the application.

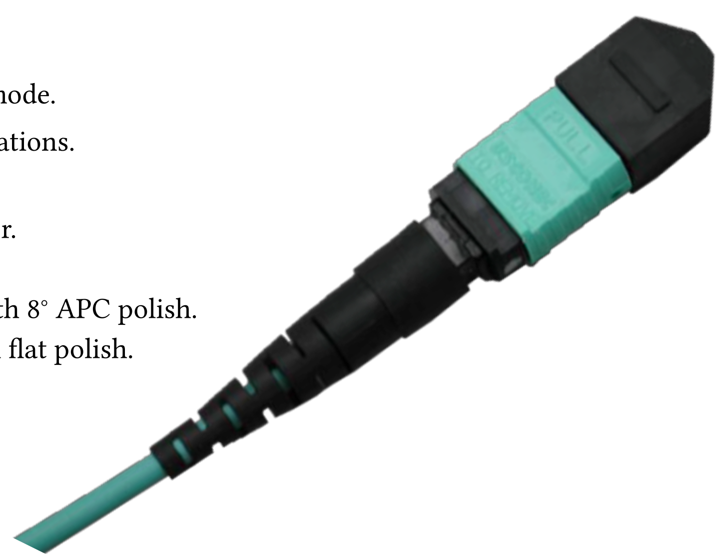
Multimode connectors are available in 4, 8, 12, 16, 24, 32, and 72 fiber densities, while standard single-mode connectors come in 4, 8, 12, and 24 fiber densities. The latest MPO connectors have 16 fibers across or two rows of 16 fibers (32 total). These designs have different pin spacing and keying to avoid mating with the more common version that has 12 fibers per row.

MPO connectors are used for a wide variety of equipment, including parallel optical transceivers, optical backplanes, optical switches, fiber-optic cross-connects, optical circuits, and high-density front panel applications. They commonly see use in public and private networks, building backbone applications, and premises cable environments. Its high density makes it attractive for data center applications.

It has specific fiber and lane assignments with numbered designations to show transmit/receive fiber locations plus unused ports. If the plug has pins, it is designated as male; if it does not have pins, it is female. It uses thermoplastic ferrules and incorporates two metal guide pins that fit into alignment holes in the mating plug.

MPO connector manufacturers each have different features in their connector designs that might impact guide pins, polarity conversions, and even male-to-female connector changes in the field.

- Also known as array connectors.
- Versions for single-mode and multimode.
- Used in data center and FTTx applications.
- MPO connector options.
  - Choose male or female connector.
  - Define fiber polarity.
  - Single-mode: Up to 24 fibers with 8° APC polish.
  - Multimode: Up to 72 fibers with flat polish.

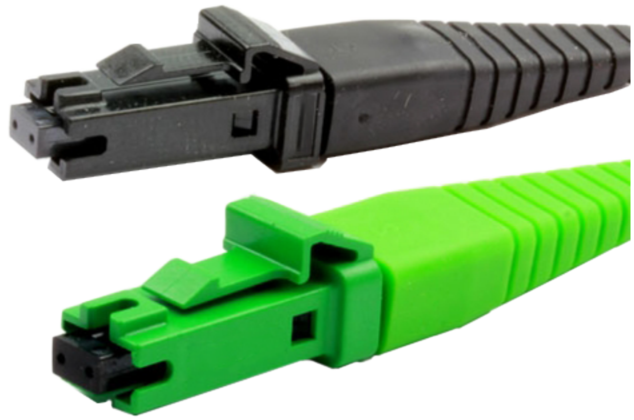


Older Connector Styles

MT-RJ

The mechanical transferable – registered jack (MT-RJ) ferrule is a duplex, push/pull, small form factor connector incorporating a reversed latching mechanism to prevent snagging fibers and jumpers. It is a multifiber connector with ten times the density of a standard SC connector, and comes in both male and female versions

The connector resembles the standard RJ-45 modular plug and the adapter uses the same hole pattern for easy conversion from existing hardware. .



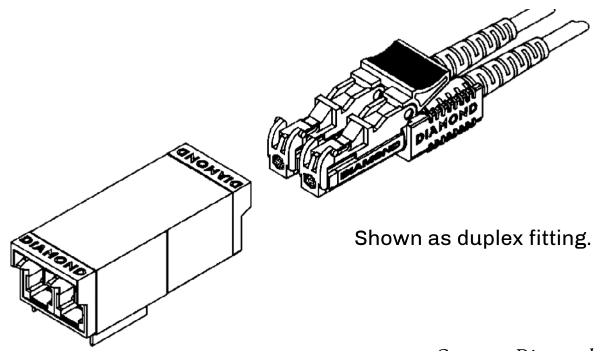
FC (Fiber Connector)

A simplex connector with keying features and a 2.5-mm ferrule, the FC continues to be a popular connector style in single-mode systems and laboratory test equipment. IEC 61754-13 and TIA-604 FOCIS-4.

DWDM Influenced Single-mode Connectors

New technology has created a demand for connectors with smaller physical profiles capable of terminating mass fibers, including ribbon fibers. Several of these new higher-density connectors from Europe include:

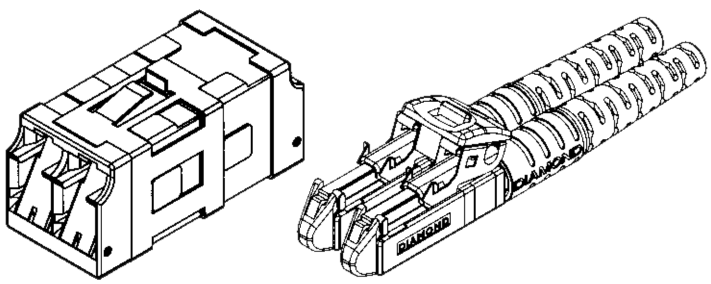
E-2000 – A push/pull connector with a 2.5-mm ferrule. It has built-in protective caps that automatically engage when the connector is removed from the system to protect the user from laser radiation and the ferrule from contamination. The sleeve features shutters that block light from the other side of the sleeve. The field-installable version connects the cable fiber to a preloaded fiber via a fusion splice for optical return loss values above 70 dB for the APC version. Manufactured by Diamond S.A. IEC 61794-15 and TIA 604-16.



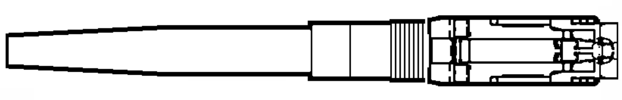
Shown as duplex fitting.

Courtesy Diamond

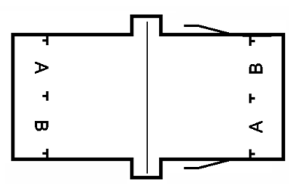
E-3000 – A push/pull connector similar to Diamond’s E-2000 model. The E-3000 features latching shutters that automatically cover the plug and sleeve when not in use. The E-3000 is LC compatible and uses the 1.25-mm ferrule. The connector is available in both simplex and duplex versions and is considered a small form factor generation connection. The connector has low attenuation and return loss and is designed for FTTx applications. Available in both single-mode and multimode versions. IEC 61794-20.



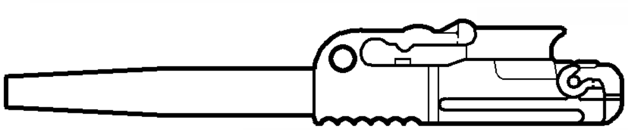
LX.5 – A push/pull small form factor single-mode connection that allows for duplex terminations in the space of a single SC housing. The plugs and adapter feature a shutter to prevent contamination when unterminated that also prevents accidental exposure to high-power lasers. Using a 1.25-mm ceramic ferrule, the connector design also uses a low-profile optical cable (0.9 mm to 1.7 mm) to allow for high-density applications including DWDM. IEC 61794-23 and TIA 604-13.



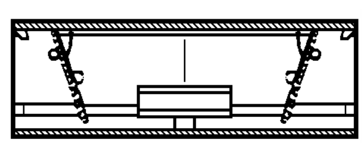
Top view of LX.5 connector



Top view of LX.5 adapter



Side view of LX.5 connector



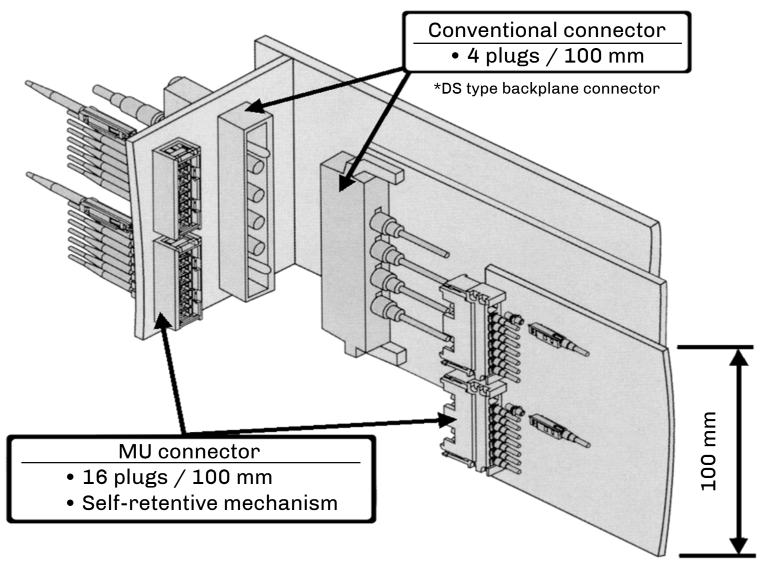
Side cutaway view of LX.5 adapter

DWDM Influenced Single-mode Connectors

(Continued)

MU – Designed as a high-performance high-density connector using push/pull coupling mechanism, the MU is available for single-fiber terminations up to eight port terminations ideal for backplane applications. The connector plug features a 1.25-mm ferrule and can be PC polished providing both low attenuation and low reflectance characteristics. Manufactured by NTT and specified by the IEC 61754-6 and TIA-604 FOCIS-17 standards.

With high-density applications becoming critical for systems, the MU is provided with different mounting features for patch panels and printed circuit boards. With up to eight sleeves in a single housing, the connector is designed for minimal compression forces.



Termination Techniques

Through the years, many techniques have been developed to improve on both the performance and the installation time for fiber optic connectors. Each technique has its own advantages and disadvantages for users. The most common types are listed below.

Thermal Cure Epoxy*

The most common connectorization technique, mostly used in factory terminations. This method uses either heat cure epoxy or five-minute (ambient) epoxy to cure the fiber into the ferrule. After curing, the fiber is scribed and polished to a fine flat end surface. Newer hot-melt styles use this technique but have the epoxy preloaded into the connector. Summary: Lower component cost, but higher technician skills required.

Anaerobic*

Two different chemical solutions are used in this technique. One solution is loaded into the connector, while the fiber is dipped into the other. When the two solutions come into contact the chemical reaction causes a bonding action that holds the fiber in position. Summary: Quick technique; contamination of solutions a problem.

Splice-on Connector

Also known as cleave and crimp connectors, this technique uses a preloaded fiber stub in the ferrule to allows the user to prepare the fiber and jacket and then cleave the fiber to a pre-established length. The fiber is then inserted into the plug and either fusion spliced or mechanically fixed into place. FuseConnects have several variations of plugs in which the optical fiber is fusion spliced into the plug to provide low-cost terminations with low reflectance values. Summary: Highest component cost, lower technician skills and cost.

Note: A fiber that will be terminated with a splice-on connector must match the first in the preloaded fiber stub.

Ultraviolet (UV) Adhesive*

Rarely used, this technique is similar to the epoxy technique, except that the fiber is bonded with a ultraviolet adhesive via the use of an ultraviolet light source, such as a lamp or sunlight. Summary: Medium cost.

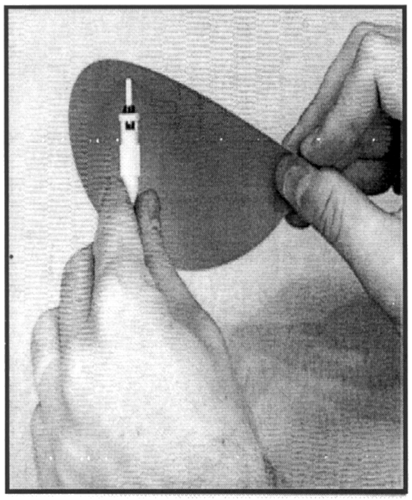
Epoxyless

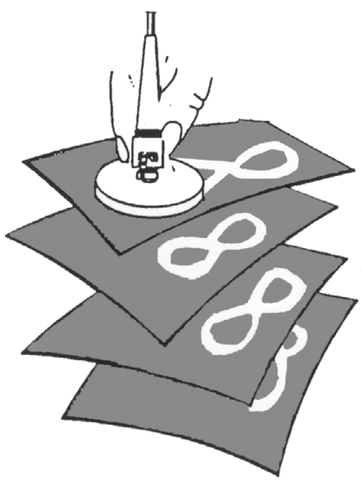
The epoxyless connectors use a unique body technique where the fiber and cable is crimped to the plug body. The plug is then mounted into a tool that forces a resilient sphere to provide a compression fit over the fiber. The plug is then scribed and polished in a manner similar to the ultraviolet and thermal epoxy types. Summary: Best used in indoor multimode applications.

* Date-coded consumable.

Connector Polishing Procedure

Polishing a plug is a series of steps starting with a coarse polishing step, e.g., 15 micron, then progressively polishing using finer lapping films, e.g., 3 micron, 1 micron, 0.3 micron.





Step A – Hold the plug body in one hand and a 15-µm lapping film in the other. Gently draw the lapping film across the exposed fiber in a circular motion. Continue this procedure until the fiber is nearly even with the plug-ferrule tip. This step is necessary to avoid crushing the fiber during the semi-rough polishing procedure.

Step B – Clean the polishing puck with an alcohol-saturated pad and insert the plug into the polishing tool. Avoid crashing the plug face against the tool during insertion. With a 3-µm lapping film, polish the connector endface using gentle, graduated pressure in a Figure 8 motion. Continue this procedure for 20-30 strokes or until a solid grey line appears on the lapping film. Clean the connector tip and inspect it with a microscope. If there is an excess of epoxy on the ferrule tip, extra polishing may be required.

Step C – Clean the connector endface and the polishing puck. Replace the 3-µm lapping film with 1-µm lapping film for the final polish. Using a gentle, graduated pressure in a Figure 8 motion, polish the connector endface for 10-15 strokes. When finished, the endface should appear free of debris or defects.

Note: Prior to Step B, clean polishing tool and glass plate with an alcohol-saturated pad, such as an Alcopad. Prior to Step C, clean polishing tool and connector endface with Opticpad.

0.3-µm Film

Substituting 12-µm, 1-µm, and 0.3-µm lapping fi lms for the above specifi ed 15-µm, 3-µm, and 1-µm fi lms may be desired. You can add the use of 0.3-µm lapping fi lm as a fourth step to the above sequence to remove any fi ne scratches or pits discovered during microscopic inspection.

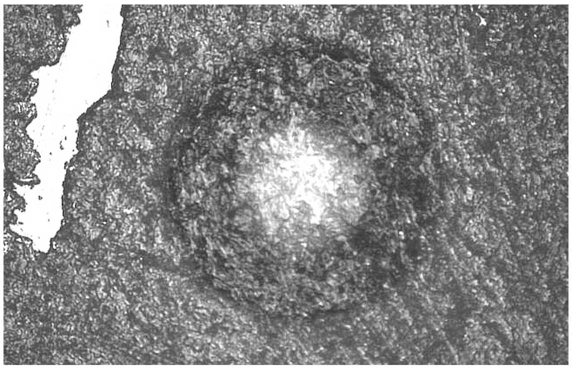
Diamond Film

Diamond lapping film may be used as a last resort to remove a deep scratch or pit, as it is abrasive enough to resurface both the ceramic ferrule endface and the optical fiber, potentially saving the terminated plug.

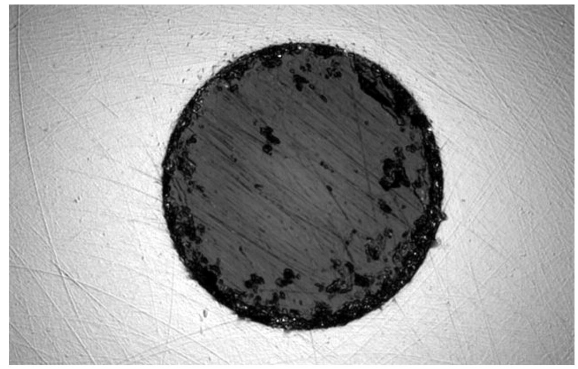
In Process Polishing Views

At 400X Magnification

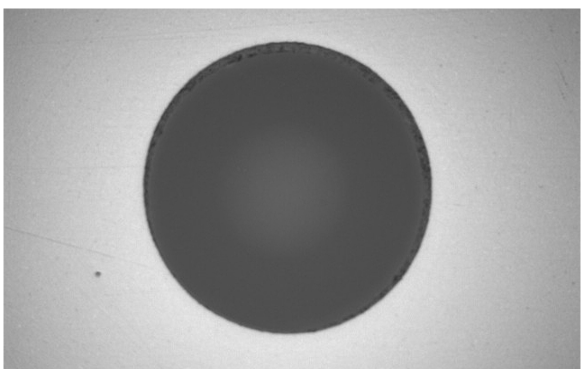
During the polishing process, the ferrule's endface will get progressively polished. At first, the epoxy on the surface will be visible. As the fiber is polished to the surface of the ferrule, any imperfections, epoxy, or debris should be removed. In multimode plugs, an epoxy ring exists between the fiber and the ferrule due to the fiber and ferrule tolerances.



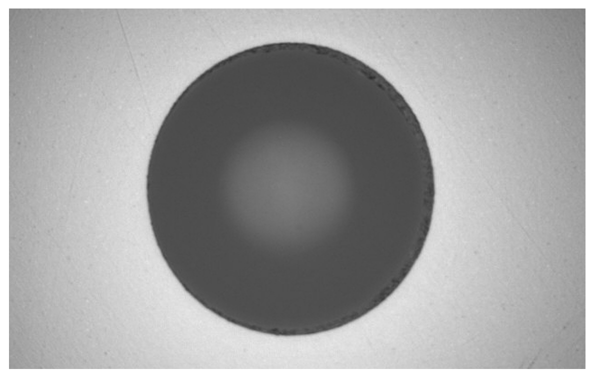
15 µm
With epoxy over fiber.



3 µm
Large epoxy ring with medium finish.

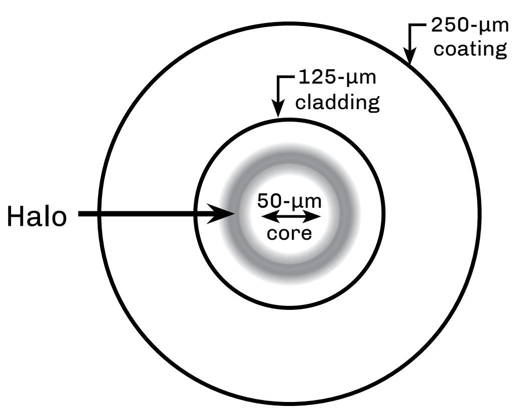


1 µm
Possible slight imperfections. Small epoxy ring between fiber and ferrule and fiber I.D.



0.3 µm
Minimal or no imperfections. Small epoxy ring.

With bend-insensitive multimode fibers, the illumination optics on the inspection scope can produce a reflection off the fiber's endface caused by the "trench" in the cladding.



Halo caused by optics from inspection scope illumination

Fiber Optic Connector Inspection

The IEC 61300-3-35 and the TIA 455-240 standards specify acceptable parameters for cleanliness and/or damage for both the fiber optic and the ferrule endface. Under these standards, any damage to the optic and the area within a specific diameter of the ferrule endface around the optic is compared to a micron-accurate, laser-etched test pattern or artifact. Based upon this type of visual inspection, field of view, microscope types and magnifications, the pass/fail criteria for scratches and pits for both multimode and single-mode fiber types can be determined.

Several work groups specified acceptance criteria for connector endface visual inspection with a consensus on magnification, resolution capability, and hardware qualification. Utilizing comparison artifacts laser-etched with micron-sized anomalies, these work groups created an acceptable set of pass/fail parameters to determine contamination and/or damage to the connector and fiber interface.

For many years, TIA-455-57B had been the accepted standard for fiber optic endface preparation characteristics. However, it was limited to low-resolution representative drawings of side views of cleaved fibers and was not specific to optical fiber endface criteria associated with connectors.

Table 1 – Measurement Regions for Single Fibre Connectors*

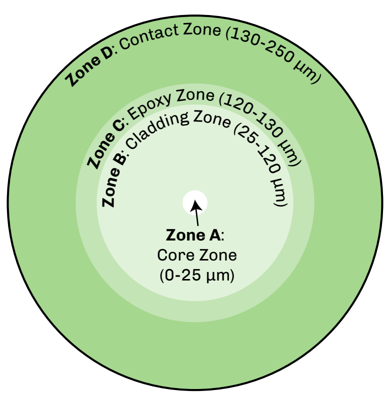
Zone	Single-mode diameter	Multimode diameter
A: core	0 µm to 25 µm	0 µm to 65 µm
B: cladding	25 µm to 120 µm	65 µm to 120 µm
C: adhesive	120 µm to 130 µm	120 µm to 130 µm
D: contact	130 µm to 250 µm	130 µm to 250 µm

NOTE 1 All data above assumes a 125 µm cladding diameter.

NOTE 2 Multimode core zone diameter is set at 65 µm to accommodate all common core sizes in a practical manner.

NOTE 3 A defect is defined as existing entirely within the innermost zone which it touches.

NOTE 4 Minor defects are allowed in the outer cladding, per Zone B.



Single-mode connector endface example from IEC 61300-3-35*

Fiber Optic Cleaning Methods

In any of the various fiber optic scenarios, it is essential that any time a fiber optic connector is disconnected from an optical port it is visually inspected for contamination or damage before it is reconnected. If no damage is found, it should be cleaned before it is reinserted into the optical port.

More than 50% of optical network failures are caused by contamination on the connector endface. Prudent planning during design and installation to accommodate well-defined cleaning practices can reduce this problem in the future.

Why we clean: Single-mode cores are approximately 8 microns (1/10th the size of a human hair) in diameter. Dust particles can impair the network by higher loss or reflection or shut it down entirely.

When to clean: Prior to inserting the connector into any optical port. It is prudent to inspect and clean any new jumper or connection, rather than relying on factory clean or others. Remember, there are two sides to every connection and both must be cleaned and inspected.

What to clean: Any optical connector endface (system, test equipment and patchcords), regardless of whether it has had a cap on it or not; and optical ports and the mated connector endface within them. Adapters can also be a source of contamination.

Fiber Optic Cleaners

Cleaning sticks, precision swabs with lint-free cleanroom-grade materials, or One-Click style cleaners are best for cleaning optical ports and connector endfaces that are mounted on the backplane. Common sizes are 2.5 mm for SC and FC, and 1.25 mm for LC-type optical ports.

Reel cleaners can be used for many types of single fiber ferrules as well as for MPO connectors. Look for specific MPO cleaners that can accommodate cleaning around the alignment pin of male MPO connectors.

The jumper side or backplane of a connection, if accessible, is best cleaned on a larger cleaning surface.

Cleaning 99.9% IPA should be limited to fusion splice preparation, as there are important differences between this and endface cleaning. IPA techniques do not ensure that a connection is properly cleaned. IPA is not recommended for cleaning connector endfaces because it leaves a film on the endface surface that increases attenuation and reflectance.

Non IPA cleaning solutions remove far more contaminants, ranging from gels to lubricants to carbon black. Some new cleaners are flammable, while others are not. There are also aqueous-based fiber optic cleaners. It is prudent to study the safety data sheets for safety concerns and environmental impact.

Visual inspection of each connection before (to identify the contaminant or damage) and after (to ensure the endface has been properly cleaned) is best practice. A light source and/or power meter are not an effective means of qualifying or quantifying cleanliness or cleaning ability of one process or another.

Fiber Optic Connector Polishes

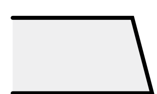
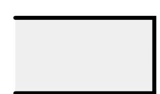
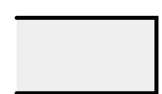
Their Relationship to Reflection

High-bit-rate digital systems and analog systems using laser sources are affected by reflections from connectors, which reflect light back to the transmitter. This backreflected light, known as Fresnel reflection, is caused by variations in the index of refraction of the light path, such as those occurring at connectors, mechanical splices, or cleaved fiber ends.

In digital systems, excessive reflections may cause an increase in the bit error rate (BER). In analog broadband cable systems, excessive reflections will show up as a degradation to composite triple beat (CTB), composite second order (CSO) distortion, and carrier-to-noise ratio (CNR), thereby degrading system performance. In more recent quadrature amplitude modulation (QAM) based broadband transmission, high reflectance can cause and increase in modulation error ratio (MER).

Factory-manufactured patch cords and pigtails control the reflectance by machine polishing the fiber endface during the manufacturing process. For single-mode connectors, the performance level of the resulting connector are designated as PC, SPC, UPC, or APC polishes. Factory-installed multimode connectors are PC-polished, and usually shipped with reflection performance of −30 to −35 dB. Hand polishing can yield a contacting connector with performance of −20 dB or better, while over-polishing can yield an air gap with reflectance as high as −14 dB. Single-mode connectors are seldom polished in the field.

Connector Reflection, by Polish

	Single-mode polishes			Multimode polishes		
	SPC Super physical contact	**UPC** Ultra physical contact	**APC** Angled physical contact	**PC** Physical contact	**Flat air gap**	**Flat contact**
						
Reflection (typ.)	−45 dB	−55 dB	−65 dB**	−35 dB	≥−45 dB	−20 dB
Light reflected*	0.003%	0.0003%	0.000032%	0.03%	> 3.2%	1%

* This measurement is a percentage of the output power of the source. In addition, the designer must recognize the loss (distance, connections, splices) from the transmitter to the device that is reflecting light. The greatest reflection is caused by the connectors at the instrument interface and the first cross-connect panel.

** Ferrule polished at an 8° angle and will have a green housing (SC or LC) and/or a green boot (ST or FC).

Single-mode Field Connectorization Issues

Unlike multimode fibers with their large cores, single-mode fibers require precision to handle the mechanical alignment, optical loss, and reflectivity concerns. Single-mode ferrules and sleeves have tighter tolerances, which provide better ferrule alignment. If you choose to terminate single-mode fibers in the field, it is best to have an ability to check the reflectance of the connector and/or use an portable interferometer to be able to confirm the polish quality.

Historically, factory-built pigtails were spliced onto the ends of fiber spans at distribution panels to provide quality connections at a low installed cost. However, more recently, newer splice-on connectors are being installed. The mating end of a single-mode fiber stub is factory-polished (UPC or APC) to meet the specified reflection value and then installed into the plug's ferrule. A bare fiber to be terminated is then stripped, cleanedm and cleaved, and the end is inserted into the rear of the plug and either mechanically fixed or fused into place. The key is a quality cleaving tool.

- Tolerances.
    - Cladding outside diameter (O.D.).
    - Core diameter.
    - Core concentricity.
    - Fiber ovality.
    - Ferrule hole inside diameter (I.D.).
    - Ferrule O.D.
    - Sleeve I.D.
- Polish and reflectivity concerns.
    - UPC or APC polish.
    - Industry standards.
- Tests and measurements.
    - Visual inspection.
    - Optical loss test set (OLTS).
    - Reflectance.

Single-mode	versus	Multimode
Small 9-µm core	versus	50-µm or 62.5-µm core
Tight tolerances	versus	Loose tolerances
PC, UPC, or APC polish	versus	Flat polish
Complex test & measurement	versus	Simple test & measurement
Ferrule inventory	versus	Same size for all
Reflection sensitive	versus	Non-reflection sensitive

Installed cost		
Factory pigtails	versus	Field termination
Splice-on connectors	versus	Field-polish connectors
High yield	versus	Lower yield

Attenuators

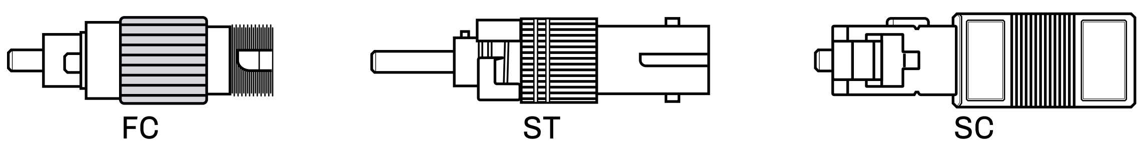
The need to add loss requires an optical attenuator. These devices are used to perform system checks as well as reduce the optical power levels into the receiver's photodetector, which can be oversaturated and create system errors or degraded circuit quality.

Most attenuators use a filter, controlled air gap, lenses, or fused fibers to increase attenuation. Remember that attenuation in fiber optics is wavelength dependent so the attenuator used should always match the transmission wavelength.

- **Requirements.**
  - Match to operating wavelength.
  - Match to fiber type.
  - Match to connector type.
  - What are tolerances (+/–)?
  - Reflective?
- **Applications.**
  - Receiver padding.
  - System testing.
  - Bit error rate testing.
  - Power meter calibration.

Fixed Attenuators

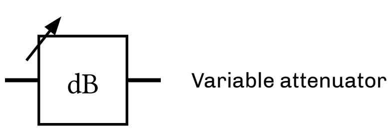
Available in increments of 1, 5, 10, 15, and 20 dB, fixed attenuators are commonly in 1 dB increments when used in analog CATV applications. Tolerances depend upon the manufacturer and type.

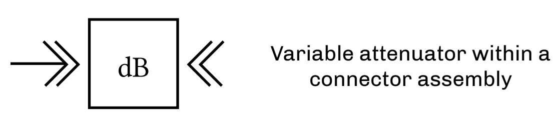


1. Receptacles with a controlled air gap or neutral density filters.
2. Plug types with built-in neutral density filters or air gap.
3. Jumpers with internal splices to specific loss values.

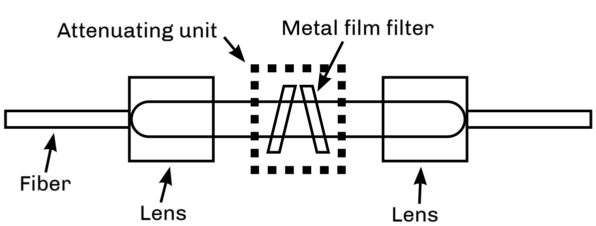
Variable Attenuators

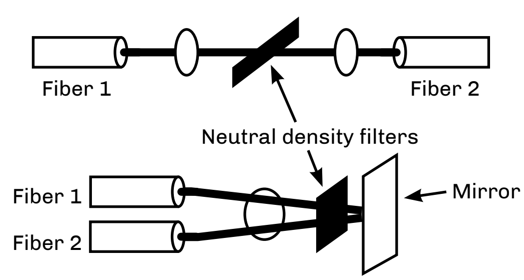
This type of attenuator is most commonly to qualify and verify bit error performance during system acceptance testing or product evaluation. The variable attenuator adds loss in either stepped or continuous methods. It will typically operate from 0 to 65 dB.





Mechanisms of Optical Attenuators





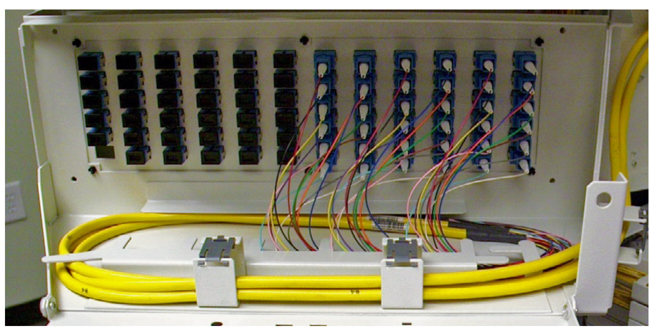
Terminators

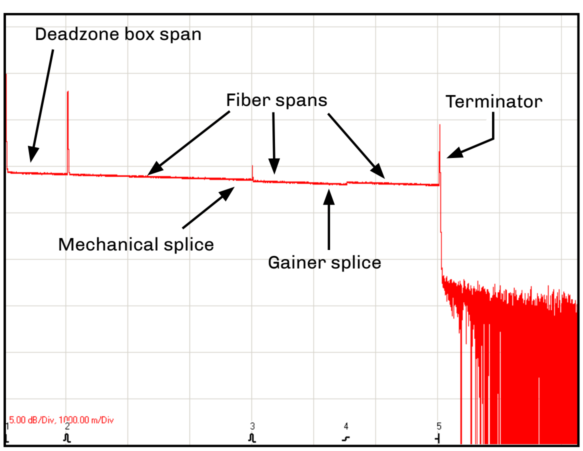
- A modified single-mode plug with the same endface geometry as the network under test.
  - Used to perform ORL and reflection tests with an OTDR.
  - Used to prevent Fresnel reflections on unused or open connector ports.
  - Available in different connector styles with UPC or APC endfaces.

How to Measure Reflectance using a Deadzone Box and Optical Terminator

- **Testing the front end connection:** The first events of reflective loss are normally hidden inside the trace's deadzone because of the OTDR's pulse width. To measure those requires a deadzone box with 20x the shortest length of the pulse width as specified in TIA-455-59, 60, and 61. For example, if the OTDR's pulse width is 10 meters, the deadzone box must have 200 meters of internally-stored fiber.

- **Testing the far end connection:** Measuring the far end of a connection requires a terminator with the same type of polished endface as the connector under test. The internal fiber is dead-ended to prevent light from being reflected. This terminator mates to the connector at the patch panel to allow reflective measurements to be taken. If a terminator or deadzone box isn't used, the resulting measurement (approximately 14 dB) will be incorrect.





This OTDR trace shows a deadzone box installed prior to the first patch panel. A deadzone box compensates for the deadzone that is created by the initial laser pulse of the OTDR and the OTDR receiver's capability to recover the normal trace after the pulse. Depending on the OTDR characteristics, the length of fiber in a deadzone box must be at least 20x the launch pulse length. Deadzone boxes need to be manufactured using the same type of fiber used in the network under test, and also contain the same type of OTDR and network connector interfaces to minimize backreflection issues.

Chapter 5 Review

1. What color is used for a UPC single-mode connector?

2. The cladding is bonded to which part of a connector?

3. What will a blue UPC or a green APC connector reduce?

4. Per TIA-568, what is the maximum connector insertion loss for use in commercial buildings?

5. What is the ITU-T G.671 attenuation value for single-mode connector attenuation?

6. What pattern should be used when hand polishing a multimode connector?

7. What other name are MPO and MTP® connectors also known by?

8. From what material are most precision ferrules made?

9. What is the ferrule diameter of most small form factor connectors?

10. What are four desirable factors to look for in a connector?

Chapter 5 Review

11. Hardened connectors are typically used in what type of application?

12. Where are minor defects allowed on the surface of a ferrule?

13. What should be done to all connectors prior to plugging them into any components or test equipment?

Chapter 6

Splicing

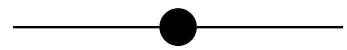
By the end of this chapter, you will be able to:

- Explain the requirements for a good splice
- Compare and contrast fusion and mechanical splicing
- List available methods for splice protection

Why Do We Need to Splice?

- Installation constraints and limitations.
- Building codes.
- Adds, moves, and changes.
- Restorations.
- Acceptance testing.
- Mid-entry splices.
- Pigtails.
- Splitters.

Fusion splice



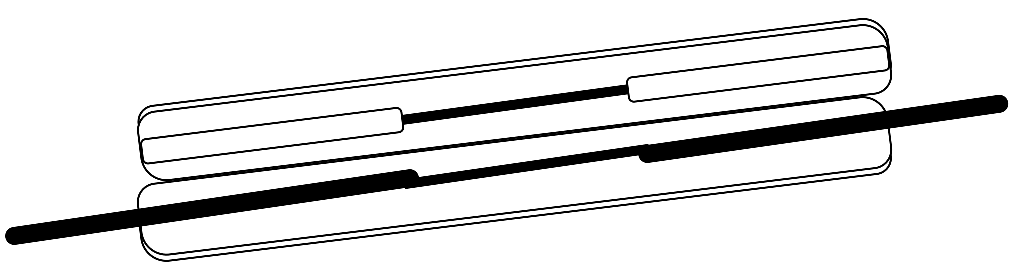
Mechanical splice

Performance

Attenuation — 0.1 dB mean average per Telcordia GR-20 and GR-765.
0.3 dB max loss per TIA-568 (premises/LAN).
0.5 dB per ITU-T G.671.

Reflectance — −40 dB per Telcordia GR-765

Fusion splice sleeve



Butterfly splice protector

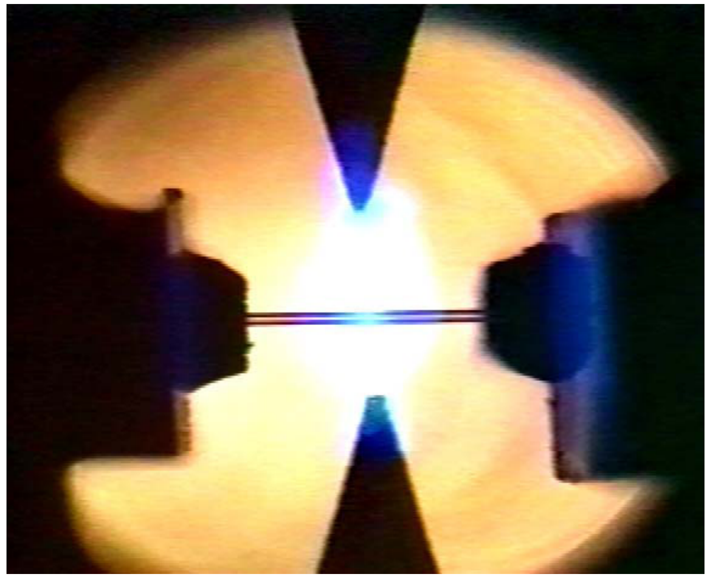
The Splicing Sequence

Most of the work involved in splicing is setting up the site, preparing the splice closure/panel, and dressing the tray. The splicing itself progresses rapidly once setup is complete.

1. Work area setup.
2. Panel/closure preparation.
3. Opening cable sheaths.
4. Securing cables (including bonding to ground, if applicable).
5. Route buffer tubes/fibers to splice trays (slack). If needed, fan out kits can be used at the splice panels.
6. Fiber splicing.
   a. Prepare fiber for splicing — length.
   b. Strip coating — clean.
   c. Cleave fiber.
   d. Place fibers in splice alignment fixture.
   e. Inspect cleave.
   f. Align or tune fibers.
   g. Splice.*
   h. Visually inspect/test.
   i. Splice protection.
   j. Route into splice tray.
7. Seal closures.
   a. Seal closure without locking down completely.
   b. Shoot fibers with an OTDR to verify that the closure is dressed and prepared correctly without stressing the fiber.
   c. Complete proper sealing of the closure.
8. Rack cable and closure.
9. Clean up and pack up.

* Mechanical splicing may require physical tuning and bonding, depending on the splice type.

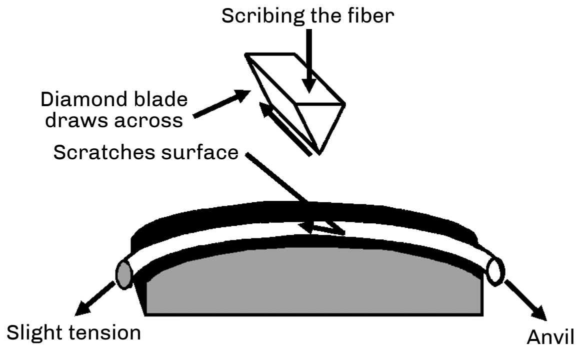
Splicing Considerations

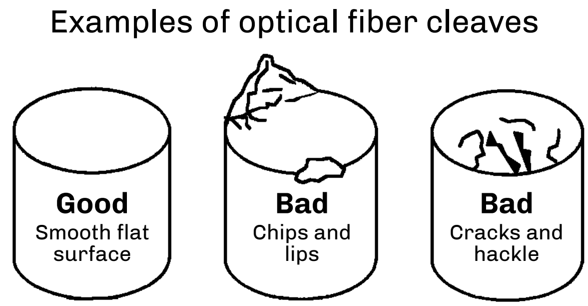


- Fiber structure.
  - Single-mode.
  - Multimode.
- Fiber tolerances.
  - Fiber core-to-core alignment.
- Quality of the cleave.
  - Good quality (less than 1°).
  - Precision cleaving tool.
- Cleanliness.
  - Clean environment.
  - No fiber contamination.
  - No tool contamination.
- System performance (reflectivity).
- Splice techniques.
  - Fusion.
  - Mechanical.
- Equipment types.
  - Core alignment.
  - Active cladding alignment.
  - Fixed V-groove.
  - Mechanical splices.
- Application (temporary or permanent).
- Environment.
  - Humidity
  - Altitude.
  - Temperature.
- Splice protectors.
  - Butterfly.
  - Heat shrink.
- Splice tray.
  - Designed for splice method (fusion, mechanical, ribbon).
  - Houses splices and optical splitters.
  - Designed for proper fiber routing.
- Technician skills.
  - Training.
  - Experience.
  - Techniques.
  - Tools.

Fiber Cleaving

Fiber optic cleavers are tools that allow the operator to scribe and break the fiber (with a 90° endface perpendicular to the axis of the fiber) with little irregularity or damage to the fiber. There are several types of cleavers available for use in lab or field environments. These tools vary in price and performance and should be chosen based on the type of splicing needed. Poor cleave angles and any other cleaving imperfections lead to added loss.





Note: Because different mechanical splice connectors (cleave and crimp style) and fusion splicers require differing cleave lengths, cleaving tools should be adjusted to the manufacturer's specifications.

Cleaving Tool Issues

1. **Cleave accuracy.**
   The more accurate the tool is for maintaining a low angle tolerance, the lower the loss will be in the splice. Cleaver blades can last for thousands of cleaves if properly maintained and rotated when they begin to wear. The tool should never experience cleaves over 1°. If so, adjustment or cleaning may be required. Cleaving ribbon fibers degrades the blade more quickly than cleaving single fibers.
2. **Costs.**
   Equipment costs can vary, but we recommend getting the best equipment possible for the job. A good cleaver will be used for a long time, providing quality preparation for splicing and achieving the best results with the least amount of time on the job. A major cost of the tool is the type of blade. Diamond, carbide, ceramic, and sapphire blades are most common, with higher-priced diamond blades being the best.
3. **Maintenance.**
   Can the tool blade be adjusted easily? Cleavers with blades that are easy to rotate and replace will also save you time and money.
4. **Exposed fiber.**
   A key factor to remember is how much fiber must be exposed during the cleave process. A tool that can be adjusted for variable lengths is ideal.
5. **Cleave length.**
   Most fusion splicers have specific cleave lengths while mechanical splices with cleave/crimp connectors have the most critical length tolerances. Specified cleave lengths are crucial for low-loss performance.
6. **Cleanliness.**
   The best method to clean an optical fiber is to use a disposable wipe or pad that contains 99% isopropyl alcohol. Stripped fiber should be cleaned properly prior to cleaving and not touched again between cleaving and splicing so as not to introduce any debris on the end of the fibers.

Common Fiber Optic Cleavers

Precision Cleaver

Used for single-mode terminations, the precision cleaver is a must for single-mode splicing. It provides optimum cleave performance and consistent <1° cleaves.

The circular diamond blade is good for approximately one to three thousand cleaves per position. Fixtures are available for 1, 4, 6, and 12 fiber counts. Optional fixtures also allow for cleaving ribbon fibers. Adjustable cleave lengths with V-grooves for 250-µm and 900-µm coated fibers.

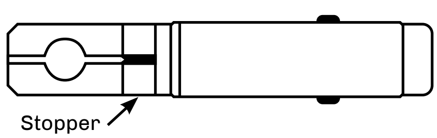
Precision Ribbon Cleaver

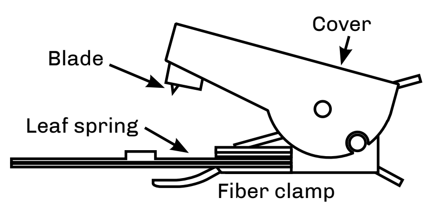
Splicing ribbon fibers requires precision cleavers, as the cleaver must scribe anywhere from two to 24 fibers at the same time. Most of these cleavers have a 16-position carbide blade with an accuracy of typical 0.5°. This allows them to perform up to 4,000 cleaves on a 12-fiber ribbon before the blade must be replaced.

Stapler Cleaver with Carbide Blade

Good for multimode splicing and single-mode/multimode acceptance testing. Not recommended for splicing single-mode fibers.

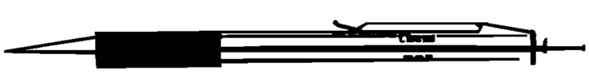
The fiber is placed across a curved surface, and a a blade is brought down to lightly scratch (or scribe) the fiber. After the blade is released and the leaf spring is bent, the fiber will break at the scored location. If improperly used, the tool will create an angled cleave.



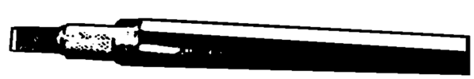


Hand Scribe

Used to scribe fibers when preparing plugs prior to polishing. Hand scribes are not recommended for splicing because they usually produce an uncontrolled angled cleave. This technique is used mainly with the connectorization process where polishing will create the final end finish.



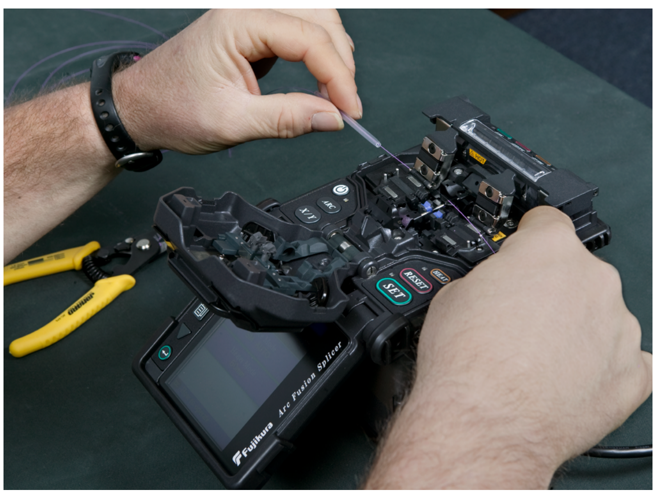
Scribe tool with diamond blade



Scribe tool with sapphire blade

Fusion Splicing

- Joins glass fibers by melting them together using an electric arc.
- Permanent, highly reliable, nonreflective.
- Can perform hundreds of splices per day in one location, depending on time required for cable preparation.
- Lowest loss when used with precision fusion splicer using active core alignment.
- Cost effective with fiber installations with large fiber counts.



Cleaning Issues

Fibers — Make sure to clean the fibers and V-grooves with alcohol. Contamination will cause misalignment and high losses. Splicing ribbon fibers requires great precision. The cleanliness of the splicer's V-grooves is critical for low loss fiber splices. Specialized brushes, fluids, and cleaning products have been developed to remove dust, dirt, and fiber coating debris from the V-grooves.

Cleavers — Use alcohol to clean the blades. Try not to touch the blade surface with bare hands, as oils from your skin will transfer to the blade. Use V-groove cleaners or a small, soft bristled brush and air to clean V-grooves and clamps.

Turn splicer ON

Confirm splice, heater, and operation modes

Clean coating or jacket of fiber

Place protection sleeve over fiber

Strip fiber

Clean fiber

Cleave fiber

Load fiber into splicer

Splicing starts automatically

Visually inspect monitor during splice

Remove spliced fiber

Center protection sleeve in tube heater

Center splice point in tube heater

Heating starts automatically

COMPLETE

Remember to order accessories,
spare electrodes, fuses,
batteries and power cords.

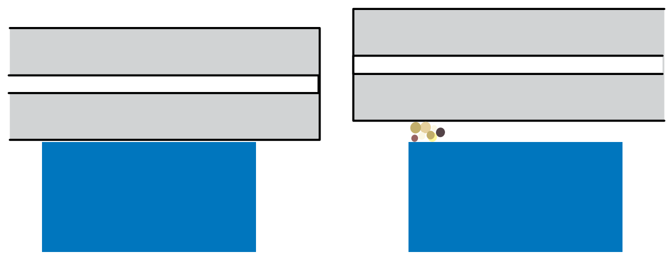
Fusion Splicing Methods

Fixed V-groove Alignment

In use since 1976, usage of the fixed V-groove or manual splicer has increased since 1992 when improved fiber tolerances of ±1 µm allowed them to achieve 0.1 dB splices with single-mode fibers. Benefits are low cost and simplicity. Fusion splicers that use this technique tend to be inexpensive. Ribbon fibers all use manual precision V-groove techniques, but are higher cost than single fiber splicers.

The fibers are placed into V-grooves on the splice machine. The accuracy is determined by the precision of the V-grooves and the fiber's core/cladding concentricity. Since there is no active alignment, the quality and cleanliness of the V-grooves and fiber can affect the accuracy.

- Accuracy determined by cladding tolerance and V-groove cleanliness.
- Used by all ribbon fiber splicers.

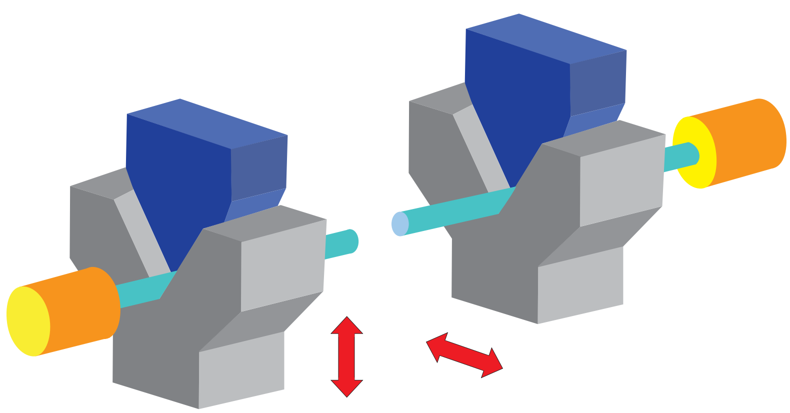


Dirt in V-grooves will impact splicing accuracy

Active Cladding Alignment

An active cladding alignment splicer moves the fibers in the X and Y axis relative to one another. This movement centers the outside diameters of the two fibers to be spliced, which compensates for differences in their cladding diameters. This can also offset the effects of contamination and dirt in the V-grooves. It cannot, however, compensate for core non-concentricity within the cladding.

These machines produce lower loss splices than fixed V-groove machines, particularly on modern fibers with good core concentricity or in cases where the equipment is not meticulously maintained.. They are also lower cost than active core alignment splicers.



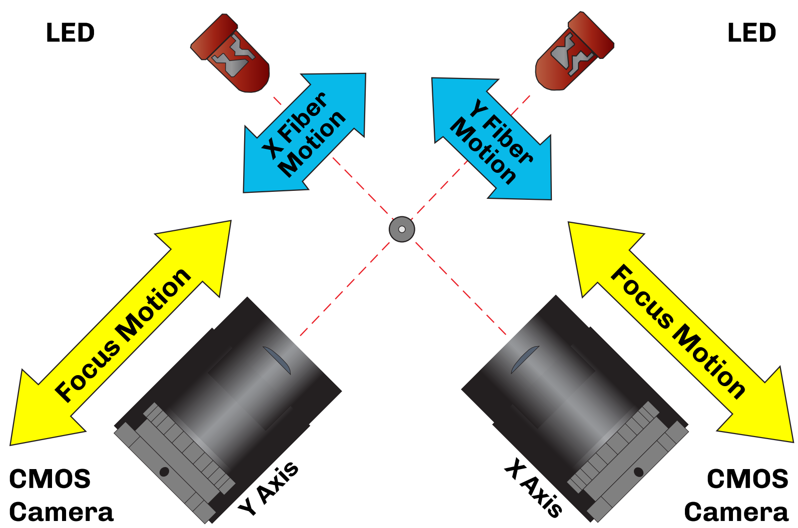
Fusion Splicing Methods

(Continued)

Active Core Alignment

An active core alignment splicer uses either two cameras or a camera and a mirror to see through the side of the two fibers to be spliced to determine the internal position of their cores. The two cores are aligned regardless of their positions in the cladding.

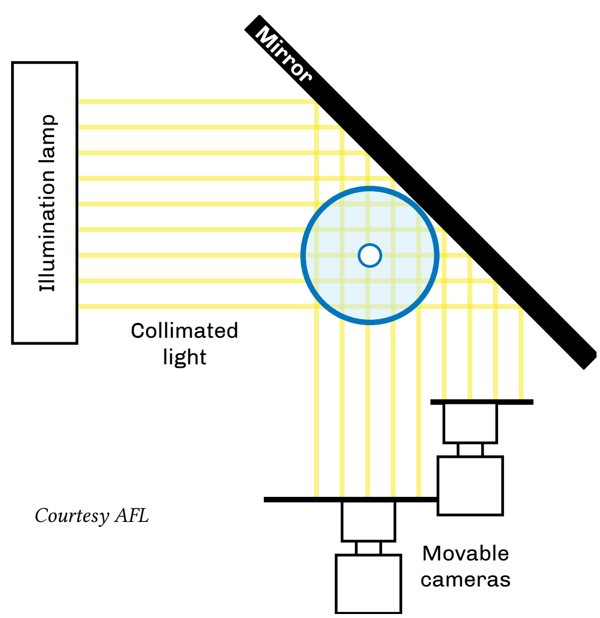
Core alignment performs much better than other alignment methods, achieving the lowest loss splices and even with used with legacy fibers. It is cited as improvement upon earlier profile alignment system (PAS) splicers that used a similar method to calculate core location, although the two terms are often used interchangeably despite performance variations between different splicer generations and manufacturers.



Profile Alignment

The profile alignment system (PAS) splicing method transmits beams of collimated light at right angles to the fiber axis at the point of the splice. Cameras produce images of the core and cladding that are then displayed on a video monitor. The core in these images are then aligned in both the X and Y axis to achieve the lowest loss.

While this can be done with only one camera, many higher-end machines employ a two-camera system. With two cameras, the splicer can more accurately align the fibers, since it can look at both the X and Y axes together. Most two-camera systems will give the user a splice loss estimation based on observed cleave angles of both fibers and the final alignment of the cores.



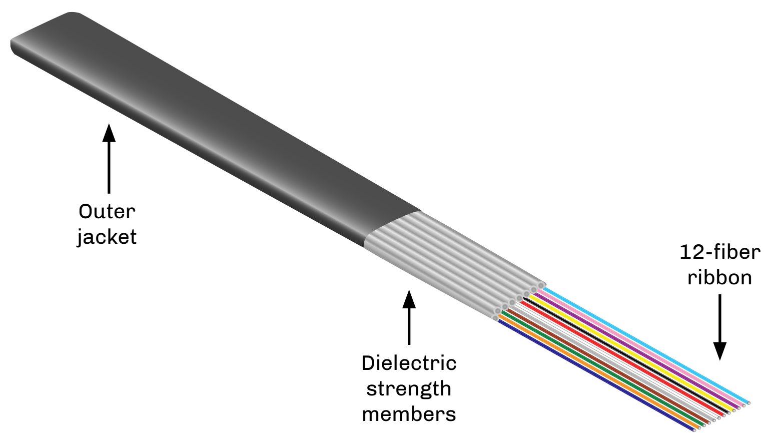
Courtesy AFL

Ribbon Splicing Technology

Ribbon fibers can be spliced using both fusion or mechanical splicing methods. Regardless of the splicing method, specialized splicers, strippers, cleavers, and other equipment will be required. Splice tray management must also be considered. Splice trays, fanouts, closures, and patch panels should all be thoroughly investigated to ensure a successful installation.

Ribbon Splicing Considerations

- **Ribbon-to-ribbon splicing.**
    - Ribbon counts.
    - Clamps.
    - Fanouts.
    - Fusion or mechanical.
- **Ribbon preparation.**
    - Stripping.
    - Cleaving.
    - Cleaning.
    - Splice protectors.
- **Tray recommendations.**
    - Splice holders.
    - Routing.
    - Protection.
- **Electrodes.**
    - Life.
    - Cost.
- **Warranty and support.**



Mechanical Splicing

Mechanical splices have been used since the early days of optical fiber technology. They provide a means of aligning optical fibers with lower losses than optical connectors. Applications include acceptance testing of fiber optic cables, temporary connections as needed, emergency restorations, and pigtail terminations.

Mechanical splices are the least expensive to use and may be reusable. They are cost effective for installations involving smaller fiber counts, and are also available for ribbon fibers. Splicing tool kits are required.

Although better than average losses can be obtained, consistency and measurable back reflection numbers are issues. Most mechanical splices use index matching gels or index matching fluids to reduce Fresnel reflections. For permanent splices, the bonding method is typically mechanical alignment and gripping or ultraviolet (UV) index matching adhesive.

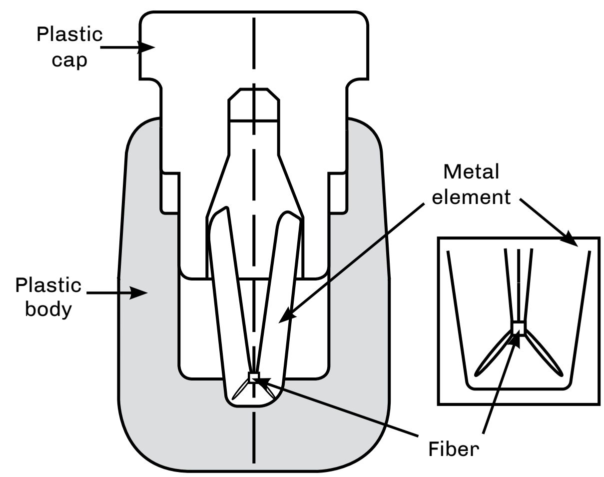
Historical drawbacks of mechanical splices have been their reflectance levels and higher attenuation values compared to fusion splicing. However, most mechanical splices have less reflection than field-terminated connectors due to their use of index-matching fluids to reduce Fresnel reflection at the fiber endfaces. They are ideal for pigtail applications such as those used in the premises industry, which is beginning to use single-mode fibers that benefit from a mechanical splice's reflection values and critical alignment. They are also ideal for security installations where low fiber counts are normal. The costs of tooling are offset by the elimination of connectorization tooling, while providing the ability to repair cables as well as terminate them.

- Reflection.
  - −45 dB per TIA-758.
  - −40 dB per ITU-T G.671.
  - −50-55 dB for SCTE for broadband analog video.
- Attenuation.
  - 0.1 dB per Telcordia GR-20.
  - 0.3 dB per TIA-758.
  - 0.5 dB per ITU-T G.671.
- Can be reusable.
- Bonding by mechanical alignment and/or UV adhesive.
- Cost effective for small fiber counts.
- Requires splicing tool kit.

Mechanical Splices

3M Fibrlok™

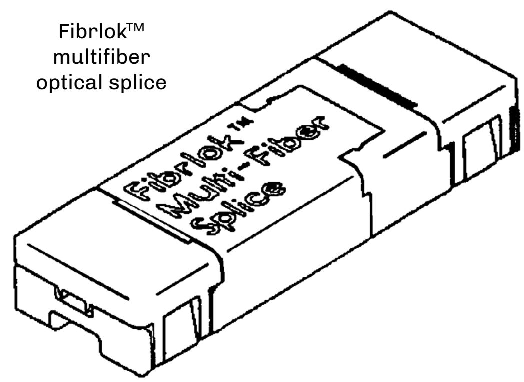
The Fibrlok™ splice uses a fiber groove that allows the fibers to position at the apex of the three channels. To lock the fiber in place, a plastic cap is pushed down forcing the three grooves to align and position the fiber on its outside diameter. The fiber is cleaved prior to insertion and is held mechanically without the use of epoxy. To reduce reflections, the splice uses internal index matching gel.



3M Fibrlok Ribbon Splicer

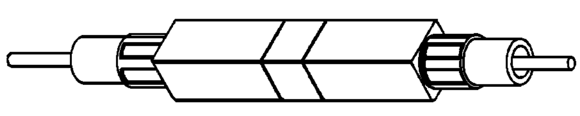
The 3M Fibrlok™ 2600 Series multifiber optical splice is a high-performance, easy-to-use, 125-µm single-mode ribbon mechanical splice. The unit simultaneously splices several optical fibers, providing secure fiber retention and environmental protection.

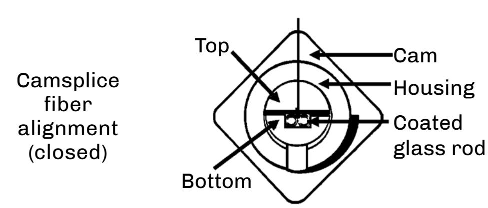
This item is factory assembled and ready for fiber insertion. It includes a malleable aluminum element that aligns and retains the fibers. The element is encased in an injection-molded liquid crystal polymer housing to supply the force required to embed the fibers. The splice is actuated by displacing a wedge on the underside of the splice. A gel-filled cover provides strain relief and environmental protection.



Corning Cable Systems Camsplice

A mechanical splice that accommodates both single-mode and multimode fibers with 250-µm and 900-µm coatings, the Camsplice incorporates an index-matching gel for low reflections and mechanically retains the fibers. An optional assembly tool is available to assist technicians.





Mechanical Splices

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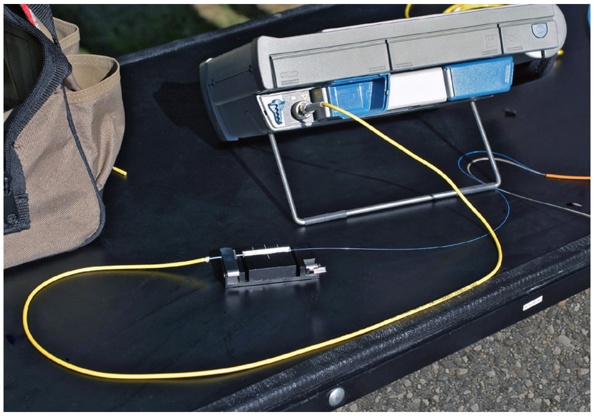
Reusable UVC Norland Splice

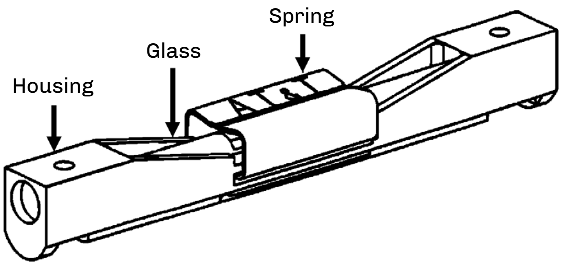


This method uses four glass rods to precisely align optical fibers. The rods are fused together to create an hollow inner core. The rods are bent at a slight angle at each end, allowing the fibers to orient themselves in the uppermost V-groove of the rods. By positioning the fiber so the ends are in the middle of the splice, the fibers can be precisely rotated for the lowest attenuation. Use of index-matching fluid reduces reflections.

Splice holders allow this type of splice to be used for temporary splices in lab and field applications. For permanent installations, the hollow section with the rods is filled with an index-matched UV fluid. After aligning the scribed fibers, the splice is cured in minutes using a UV lamp.

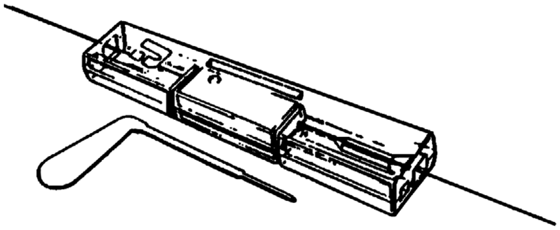
CSL Splice

This splice consists of three elements that mechanically hold two fibers in alignment without the use of UV adhesives. A clear plastic housing allows visual inspections of the fiber during splicing. The second element is a Pyrex (glass) capillary that is preloaded with index-matching gel and has offset bores for fiber alignment. Finally, a spring clip locks the fibers into place.



Corelink

A mechanical splice that uses V-grooves to maximize fiber positioning and alignment, the Corelink design uses a key, which can be inserted and turned 90° for fiber positioning. When the key is removed, the V-grooves compress and position the fiber. The splice encompasses index-matching fluid to lower reflections. An adjustable cleaving tool is required due to the different strip lengths necessary for 250- and 900-μm buffer coatings.



Pigtail Splicing and Splice-on Connectors

Use of pigtails — short cable assemblies with a connector on one end — is common practice for many applications. Indoor and outdoor panels can include splice trays that will hold the splice sleeves when bulk cable is transitioned to a patch panel. Whether you are terminating single-mode or multimode fiber this way, consider these key points:

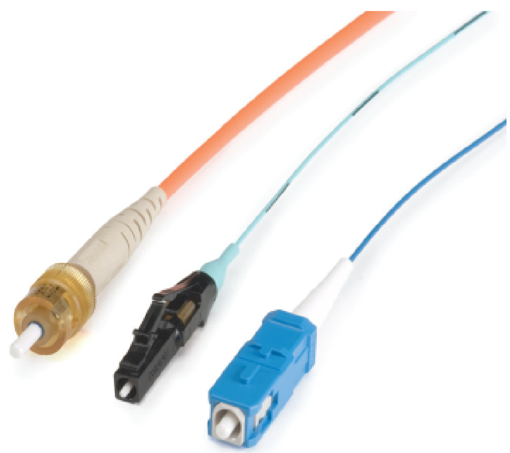
- The fiber in your pigtails should be the same type of fiber as the cable you will splice to.
- If you use jacketed pigtails (1.6 mm, 2.0 mm, etc.), they will be color coded by fiber type and not as the standard individual color codes – so you will need to label them.
- If you use 900-micron pigtails, you can continue the color code if you can order all the right colors. Otherwise, you will also need to label them.
- Specify your connector types properly, matching the adapters that will be in your patch panels.
- Order connectors based on the loss and reflectance requirements of your network.

Field Splice-on Connectors

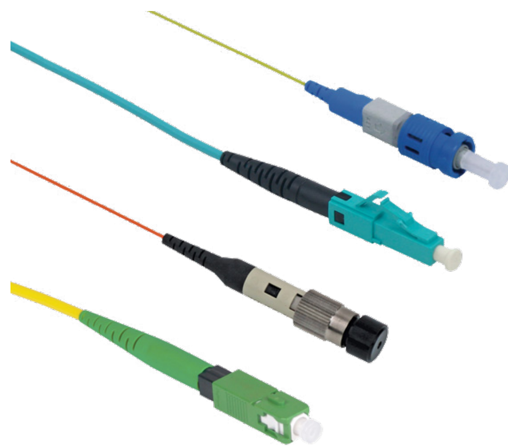
Mechanical splice-on connectors have been a common way to make field terminations for years. These pre-polished connectors eliminated the need to terminate, cure, and properly hand-polish a connector in the field — which was time consuming and often had poor results.

Although a mechanical splice point might add a bit of reflectance to the link, the high-quality polish of the connector itself provided very good loss and backreflection results.

Fusion splice-on connectors are another great option for anyone with a splicer, allowing for field terminations with very low loss and reflectance values. These connectors are available from many vendors, and once equipped to install them, they can provide a significant time savings in the field, with very good performance results.



UniCam® mechanical splice-on connectors



FUSEConnect® fusion splice-on connectors

How Do We Protect the Splice?

Level 1	Protect the splice	• Protectors		
			• Heat shrink	40 mm/60 mm/ribbon
			• Butterfly	250/250 – Yellow
				250/900 – Blue
				900/900 – Green
Level 2	Protect the fiber	• Splice trays		
			• Single	
			• Ribbon	
Level 3	Protect the fiber, splice, and tray	• Splice closures		
			• In-line	
			• Butt style	
Level 4	Protection for inside buildings	• Splice panels		
			• Wall mount	
			• Rack mount	

Miscellaneous Issues to Address

- Fiber and unit (buffer tube) identification.
- Documentation.
- Restoration kits.
- Mid-entry splices.
- Future changes.
- Bidirectional loss values.
- Power.
  - Generators.
  - Batteries.
- Analog/digital signals.
  - Reflectivity.
- Cost versus performance.
  - 0.05 dB.
  - 0.10 dB.
  - 0.15 dB.
  - 0.20 dB.

Chapter 6 Review

1. What is the maximum splice loss per Telcordia GR-20 and GR-765?

2. What type of reflection does index matching gel reduce?

3. How are most single-mode fibers terminated in the field?

4. Achieving a good cleave requires the cleaving blade be held at what angle to the fiber?

5. What are two types of splice protectors?

6. How are most single-mode fibers terminated before they are spliced to the cable's fiber ends?

7. True or false: The loss that results from poor polishing, cleaving, or cleaning is classified as extrinsic.

8. True or false: Mechanical splicing is most common in emergency restoration applications.

9. True or false: Fusion splicing is the primary solution for single-mode applications.

10. What are the three types of fusion splicer technologies?

Chapter 6 Review

11. What type of deployment has returned fixed V-groove alignment fusion splicers to prominence?

12. True or false: Arc temperature or burn-back test should be conducted as needed, but specifically any time there is a humidity or altitude change.

13. Great care should be provided when dressing in splice sleeves and fibers to prevent inducing what?

Chapter 7

Fiber and Cable Management

By the end of this chapter, you will be able to:

- Explain the basic methodologies of fiber management
- List and describe various types of panel storage products
- Explain the purpose and applications of a splice closure
- Summarize the benefits of using a splice tray
- Compare and contrast fanout kits and breakout kits
- List types of outside plant cable management products, and describe where each might be installed

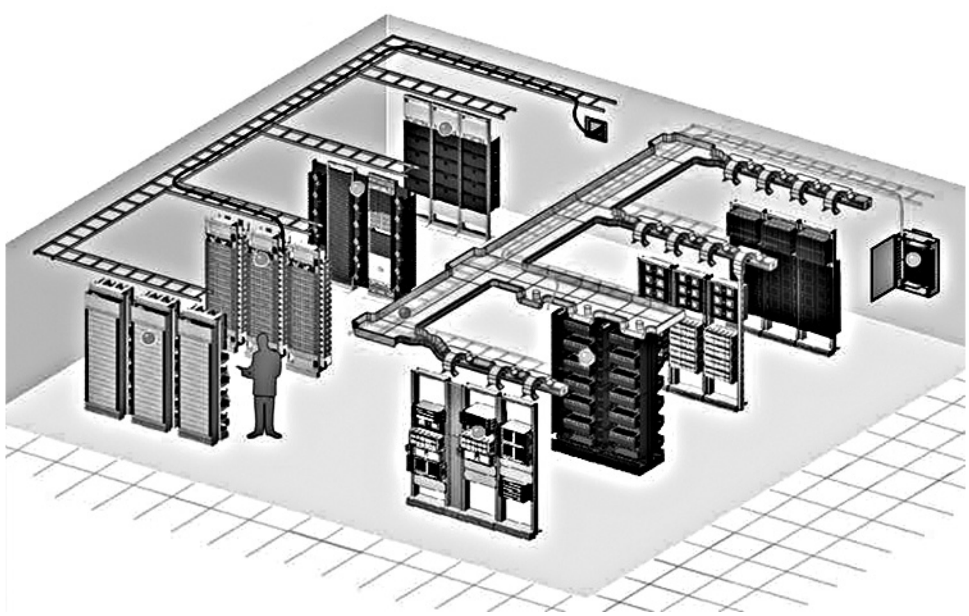
Fiber and Cable Management

Hubs and Premises

For inside building applications, there are two basic types of mounting commonly used. Hub sites such as central offices and head-ends will typically use racks to mount single-mode splice, patch, and distribution panels, along with transmission equipment. They may also use wall-mounted storage and splice panels to increase flexibility and simplify internal cable routing.

Premises and data centers tend to use racks in hub sites and wall-mounted panels in remote locations. Generally, multimode fiber is used, but single-mode fiber is seeing more deployment as data rates increase. For premises installations, the structured wiring terminology in TIA-568, TIA-569, and IEC 11801 is used.

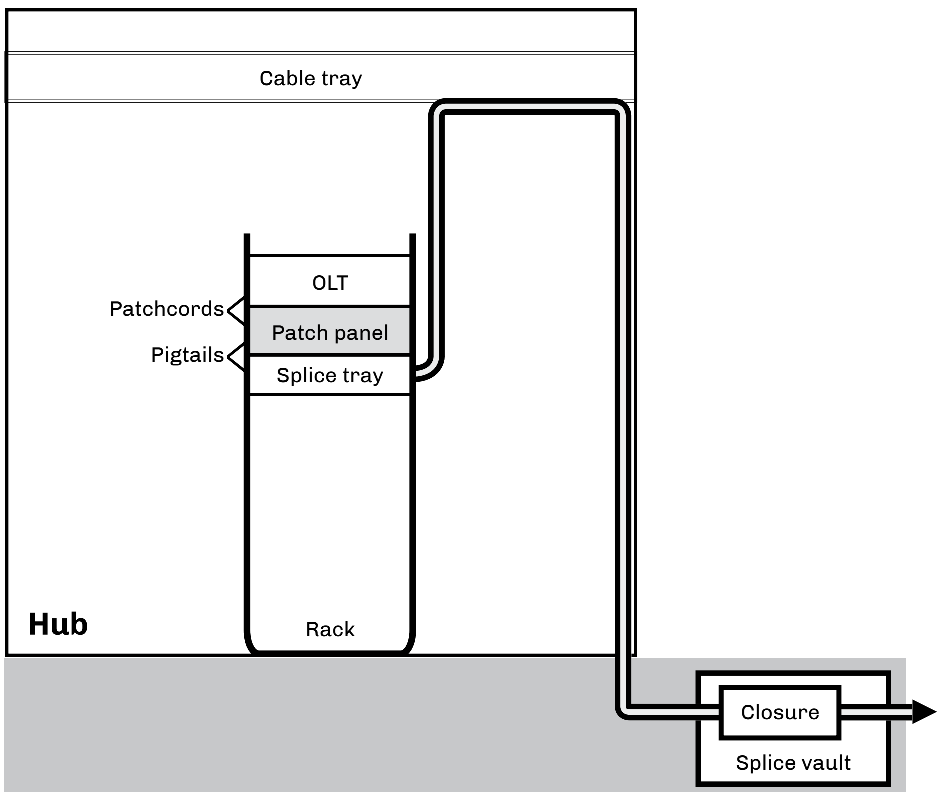
Description	Telco/CATV applications	Premises applications
Fiber distribution frames (patch panel) Rack mount	Central office Headends Nodes	Intrabuilding Intermediate (IC) Main cross-connect (MC)
Distribution panels Rack mount	Central office Headends Nodes	Building entrance Hub Main cross-connect (MC)
Splice panels Wall mount Rack mount	Building entrances (Entrance facilities)	Building entrances Entrance facilities
Optical entrance enclosures (OEE)	Central office Headends Entrance facilities	Building entrances Entrance facilities
Premises panels Wall mount	Entrance facilities	Intrabuilding Intermediate (IC) Main cross-connect (MC)



Fiber Management

Traditional Installation

Loose tube cable is spliced at the outside cable vault and routed into the building. If the distance inside the building exceeds 50', the cable must be placed inside electrical metallic tubing (EMT) per NEC Article 770. The cable is routed to the correct rack and then to the splice panel. If there are metallic members in the cable they must be grounded per NEC Article 250. The internal fibers are then routed to the splice tray via buffer tubes or transition tubing making sure the internal fibers are protected. Pigtails are spliced to these fibers via the splice trays. The pigtails are then properly installed and routed making sure no macro or microbends are present.

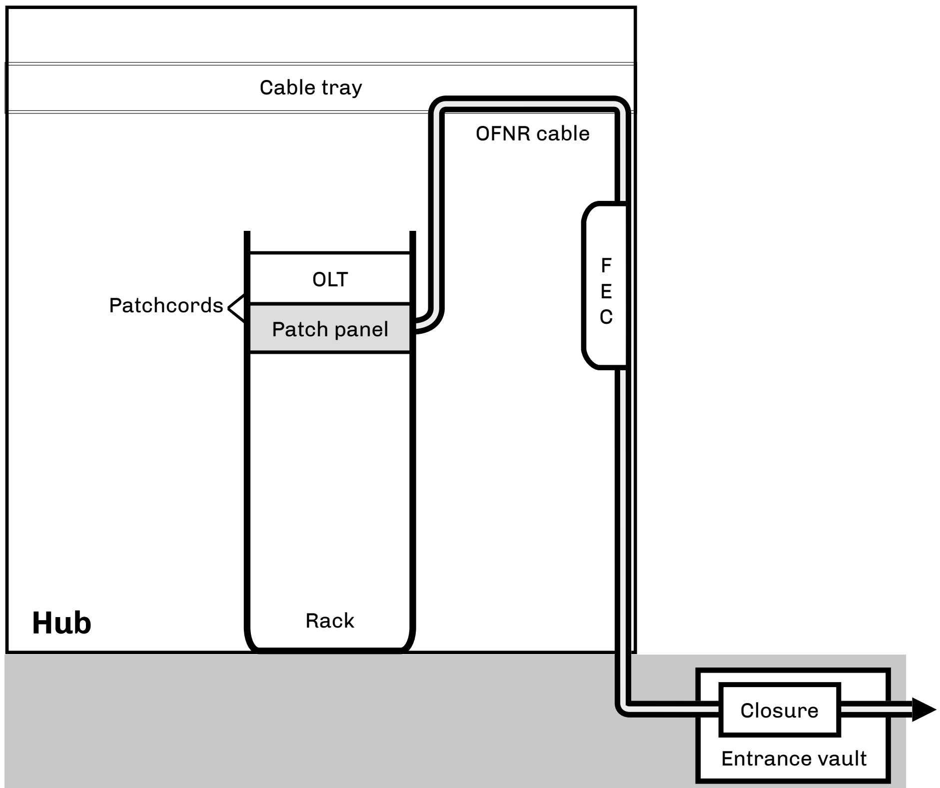


- Loose tube cable is spliced at the outside cable vault and routed into the building.
- Cable is routed to the correct rack and then to the splice panel, where internal fibers are routed to the splice tray via buffer tubes or transition tubing.
- Pigtails are spliced to these fibers via the splice trays and connected to the patch panel.
- Patchcords and jumpers are used to link transmission equipment.

Fiber Management

Preterminated Patch Panels

Loose tube outside plant cable is routed to a wall mount fiber entrance cabinet (FEC). The patch panel has been ordered with the correct connector type (e.g., SC) and polish (UPC or APC) and a predetermined length of NEC-rated cable (OFNR or OFNP). The panel is mounted in the rack and the cable stub is routed to the FEC via fiber optic cable trays where it is spliced to the incoming outside plant cable. This technique saves rack space, has a lower installed cost, and centralizes all splices in one convenient location.



- Loose tube cable is routed to a wall mount fiber entrance enclosure (FEC).
- Patch panel is mounted in a rack and the preterminated cable stub is routed to the FEC and then spliced to the incoming cable.
- Saves rack space, has a lower installed cost, and centralizes all splices in one convenient location.
- Eliminates NEC transition problems.

A preterminated patch panel

Rack Space

As bandwidth consumption has increased, the demand for additional fibers continues to grow. However, the amount of physical space available to house those fibers is often a problem. Proper management of rack space is important to meet these growing demands for density.

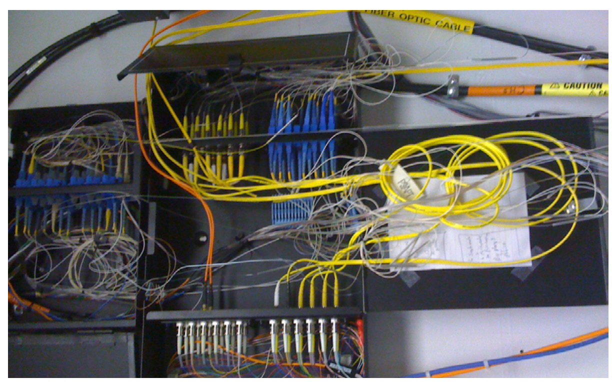
Racks are listed in terms of rack units (RUs), which is measured in height. For example, a 1RU panel is 1.75 inches, and a 2RU panel would be 3.5 inches. A full size rack is 6 feet (1.8 meters) and can accommodate 42 RUs. This can be either 19 inches for data communications cabinets, or 23 inches for standard telephony installations.

Connector Density Comparison

	1RU	2RU	4RU
LC – Standard density	72F	144F	288F
LC – High density	144F	288F	576F
MPO/MTP	576F	1152F	2304F

Connectors also play a major part in density. The SC, LC, and MPO push/pull connectors have all been designed for ease of coupling by the user. However, density is the major reason why high-density connectors are needed where transmission equipment and fiber management products are installed. While the SC connector is better for those with large hands, the LC has double the density of a standard SC connector.

- Good cable management.
  - Provides organization.
  - Greatly reduces or eliminate related attenuation.
  - Provides a clean and defined pathway for patch cords and cables.
  - Reduces maintenance and administration time.



- Bad cable management.
  - Dirty connectors add unneeded attenuation and reflection.
  - Includes excessively long patch cords for short distances and tight tie wraps coiled around extra slack.
  - No cable management product in place to provide weight support.
  - No defined path for patch cords to follow.
  - Lack of or improper usage of labels.

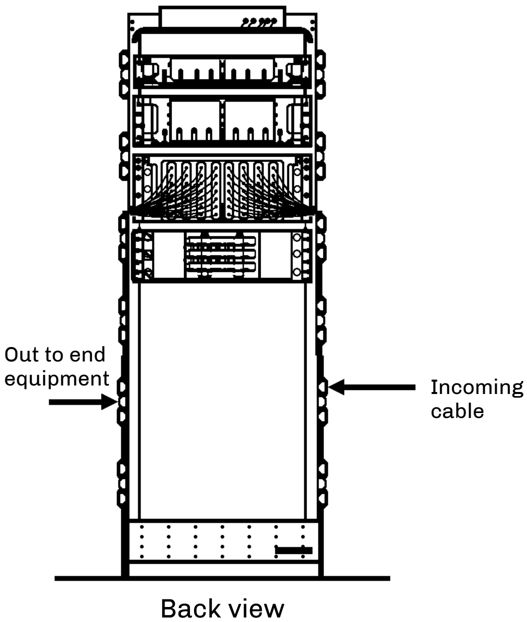
Patch Panels

Intermediate and Main Cross-connects

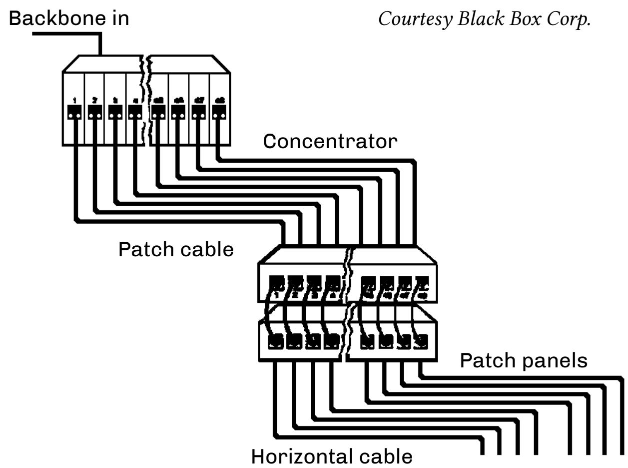
IC and MC patch panels provide a central location for patching, testing, monitoring, and restoring service to fiber-optic transmission lines. The patch panel receives the fiber optic patchcords or jumpers from the splice panel or from equipment and properly routes it to other pieces of equipment.

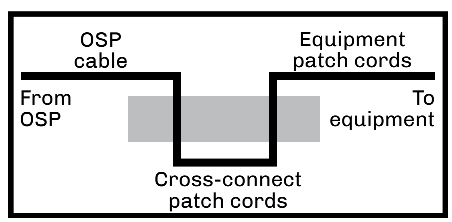
Patch panels can be main cross-connects or intermediate cross-connects. Personnel can access backbone cabling in intrabuilding links and transmission equipment. Patch panels are available with various types of connector options. Preterminated patch panels routed to optical entrance enclosures allow for easy installation.

Courtesy TE Connectivity



Courtesy Black Box Corp.





- Centralized location for patching, testing, monitoring and restoration.
- For LANs the patch panel may be the main cross-connect (MC) or an intermediate cross-connect (IC) point.

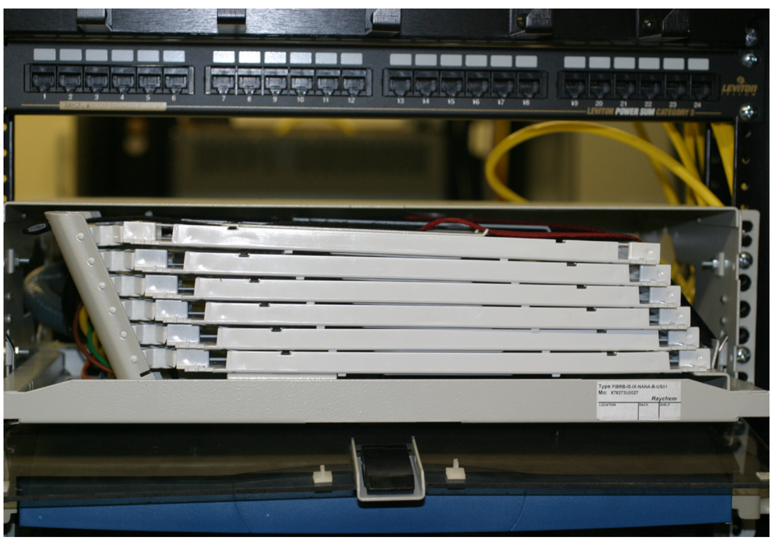
Splice Panels

Splice panels allow the user several options to route fiber optic cable and are most commonly used in two locations:

1. As a transition point between outside plant loose tube single-mode cables with 250-µm coated fibers and pigtails with 900-µm coated fibers. These panels are most often mounted in 19” racks either above or below the patch panel or integrated within a patch and splice panel.
2. As an optical entrance enclosure, normally wall-mounted at an entrance facility where the required National Electric Code transition point is made.

In order to meet the NEC’s requirements for a transition from outdoor cable to indoor tight tube cable, the outdoor cable must be terminated or spliced within 50 feet (15 meters) of the building entrance unless enclosed in grounded rigid metal conduit (NEC 800-40(b)).

It is also important to check the requirements for the distribution of cables to various equipment rooms, buildings or cross-connects in a site. In many cases, controlled room access or locks may be required.



Rack mount splice panel

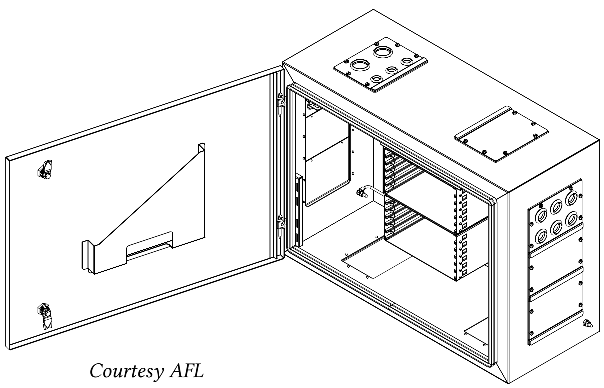
- Entrance facility or rack mounted.
- Facilitate distribution of fibers and/or cables to various equipment rooms, buildings, or cross-connects.
- Must use appropriate splice holders and trays and accommodate proper bend radius.
- Transition point between outdoor and indoor cables.

Optical Entrance Enclosures

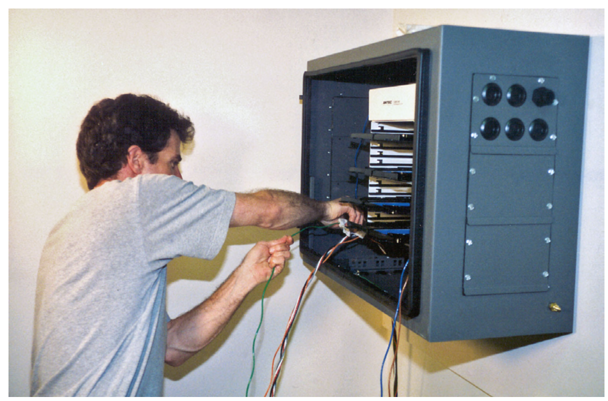
Wall Mount

Optical entrance enclosures provide a convenient splicing and interconnection location for outside plant cabling entering a central office, controlled environmental vault (CEV), or customer location. They are designed to allow the entrance and management of up to 60 cables for splicing and interconnecting. Cables from termination locations and the outside plant are easily installed and managed. Access to individual fiber splices and fiber bundles is made easy by splice tray and fiber management designs. Other features include:

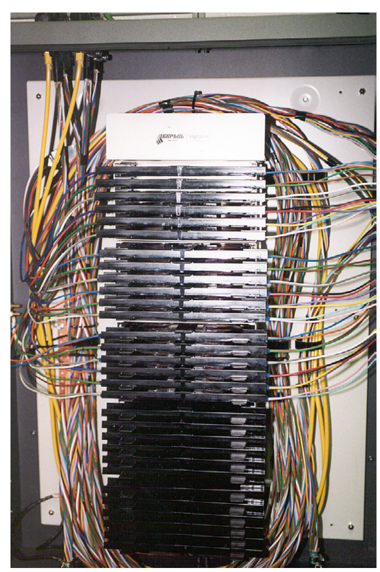
- Provide a transition point between the OSP and internal rated cables.
- Consolidate splicing in one location.
- Save rack space.
- Multiple cable entrance ports to accommodate routing and growth.



Courtesy AFL



Entrance Facilities



Depending upon the application, access to the outside plant can be provided through a variety of options and products to best meet the designer's requirements:

1. Installation of a patch panel and routing pigtails to a splice panel.
2. Installation of a distribution panel with both patching and splicing capabilities.
3. Installation of a fiber management bay with both patching and splicing capabilities.
4. Installation of a preterminated patch panel with a known length of cable routed to a splice panel located at the entrance facility.
5. Installation of a preterminated patch panel with a known length of cable routed to a splice closure at an entrance vault.

These options require an understanding of each of the product types and usages from the entrance facility back to the transmission equipment. The entrance facility provides a transition between outdoor loose tube cables and indoor cables when using a splice panel.

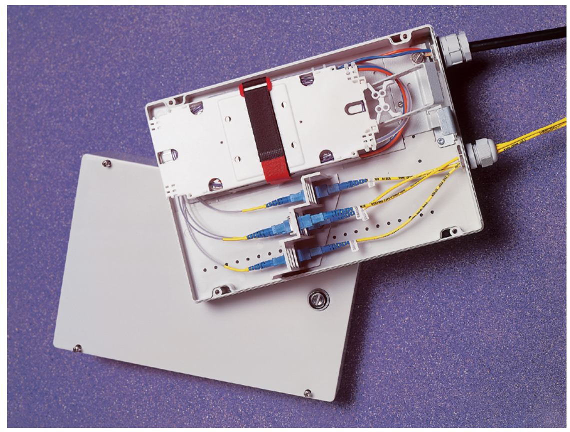
Fiber Distribution Units

Main Cross-connects and Entrance Facilities

The fiber distribution unit (FDU) is a panel with splicing and patch functions combined in the same unit. Connector and splice trays may be removable for convenient access for maintenance, testing, and splicing. Available with both 19” and 23” mounting brackets. Cables are normally secured at the panel with buffer tubes routed to splice trays where pigtails are spliced and routed to numbered six-packs and adapters.

Wall-mount distribution center

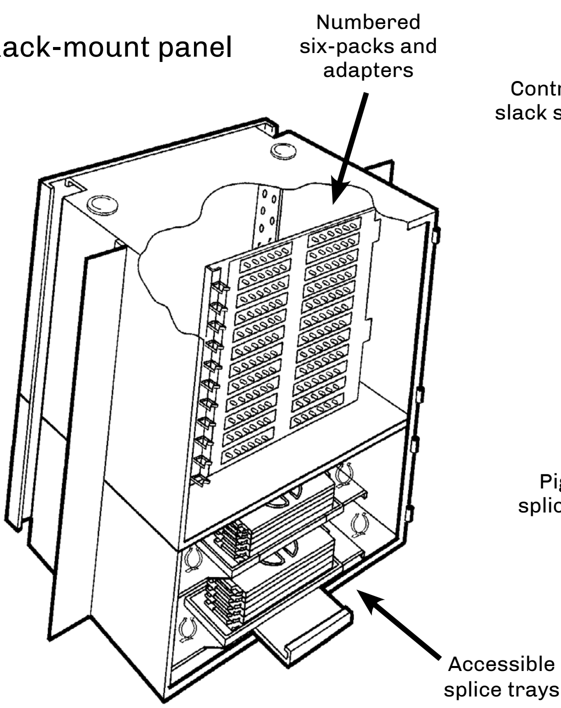
Courtesy TE Connectivity



Wall-mount distribution enclosure

Courtesy TE Connectivity

Rack-mount panel



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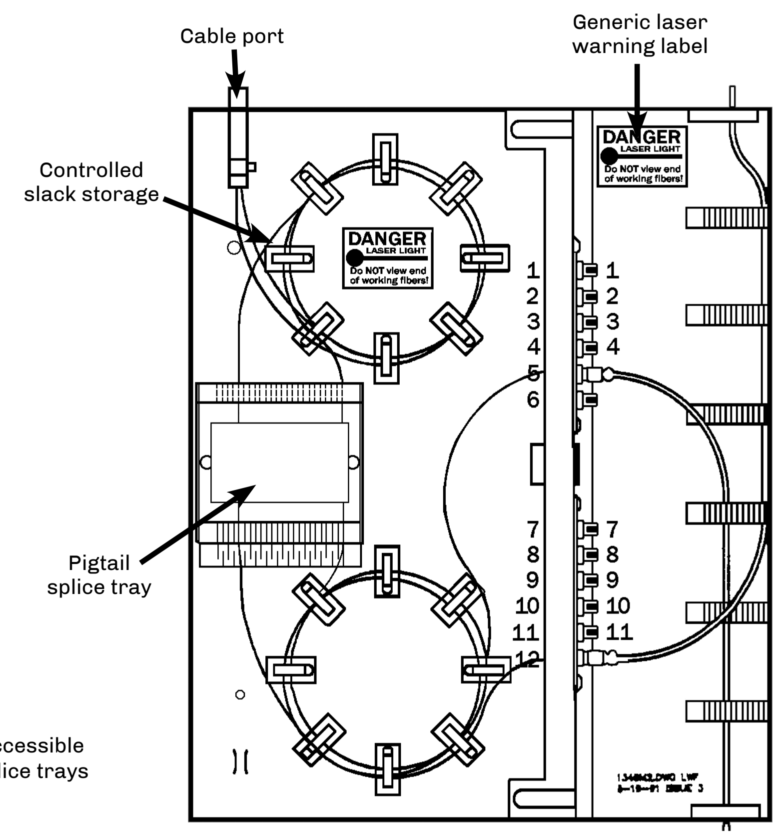


Wall-mount fiber distribution panel

Splice Closures

Designed for splicing optical cables together from one reel to another after installation, a splice closure can allow splitting or routing of fiber cables from multiple locations. The closure may permit either a butt or in-line splice application. The fiber optic cable's strength member(s) must always be secured to the splice closure, in accordance with the manufacturer's specifications.

The closure must be environmentally sealed to protect the fibers from water intrusion and potential freezing. After sealing the closure, perform a pressure/flash test (normally at five pounds of pressure) to confirm proper dome and cable entrance port sealing. Closures should also be re-enterable.

Courtesy TE Connectivity

The Telcordia GR-771-CORE, titled "Generic Requirements for Fiber Optic Splice Closures", is a comprehensive specification with which closures must comply. The standard includes features and functions such as cable compatibility, cable entrance capacity, cable termination hardware, bonding and grounding hardware, fiber and splice organization (including minimum bend radius, as well as fiber and splice protection. Performance requirements for electrical (bond clamp retention and AC fault tests), mechanical (cable clamping, sheath retention, cable flexing, cable torsion, vertical drop, compression, impact, and central member retention) and environmental concerns are also included.

The Necessity for Excess Fiber Length

1. To allow resplicing due to errors in splicing fibers.
2. To allow the fiber ends to reach the fiber work station or fusion splicer.
3. To accommodate fiber movement by creeping or thermal changes.
4. To allow single fiber splices in ring networks.

Splice Closure Applications

- In-line splicing.
- Mid-entries.
- Restoration splicing.
- Splitter function (FTTx and HFC).
- Cross-connects.
- Optical add/drop multiplexing.
- Butt or inline styles.

Courtesy TE Connectivity

Splice Closures and Transition Tubes

Due to the versatility and importance of the splice closure, it is critical to consider its intended use, application, and environment over its lifespan. How much cable should be slacked within the closure?

Normally you would want to store as much as possible to address future adds, moves, and changes. Remember that buffer tubes can be pinched easily so that proper dressing (or routing) of the buffer tubes should be performed carefully. If buffer tubes and closure design do not allow proper installation of the buffer tube(s) to splice tray, a transition tube may be required.

Mid-entries require only one buffer tube to be entered. Remember to order a storage tray for holding unopened buffer tubes.

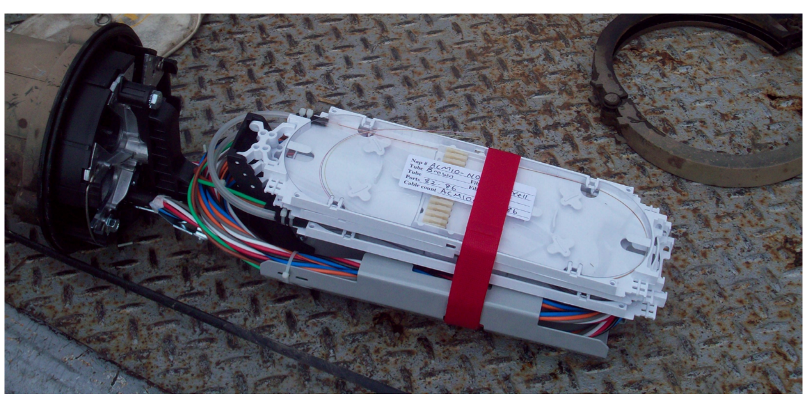
Closure Issues

Bonding and grounding
Mid-entry capability
Buffer tube routing
Environmental sealing
Re-entry
Size and space
Ribbon routing
Splitter mounting
Cable strain relief
Tools
Growth
Transition tubes
Drop ports

Splice Closure Transition Tubes

Splice closures use transition tubes for a variety of reasons:

1. **Fiber protection.** If a splice closure has hinged or movable splice trays, transition tubes should be applied over any exposed buffer tubes or fibers to keep them from kinking or pinching during movement, as they are generally very rigid.
2. **Mid-entries.** Fibers may need to be distributed from one splice tray to another and will need to be protected. Transition tubing should be applied over any bare fibers and secured to the splice tray like a buffer tube.
3. **Splitters.** A 1:8 splitter requires nine (or more) spaces for the splitter (FBT, module, or cassette) and the pigtail splices. A 1:16 splitter would require 17 and the splitter package. This would mean two splice trays with a transition tube to route and protect the fibers.



Opened splice closure with storage tray for mid-entry applications

Splice Closure Types

OSP Closures

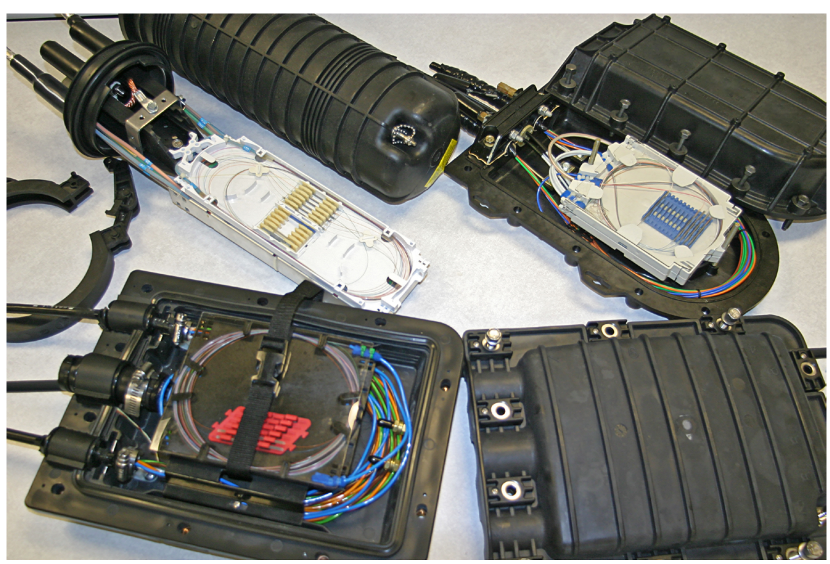
- High fiber counts.
- In-line or butt style.
- Larger.
- Environmentally sealed.
- OPGW and ADSS.

FTTx Closures

FTTx/PON splice closures are designed for use with splitters and mid-entries. Fusion splicing the network together to maintain low losses, these small closures provide a stable environment for slack storage, splitters and the splices by housing them in a permanent encasement. A variation of FTTx closures known as multiport service terminal (MSTs) have evolved with a hardened connector interface inside the closure assembly that allows customer subscriptions to be diverted until the customer signs up. Internally, pigtails from these connections are routed to splice trays.

Whether closures are located at drops or mid-entries, in vaults or enclosures, proper environmental sealing is critical to prevent invasive exposure to the elements.

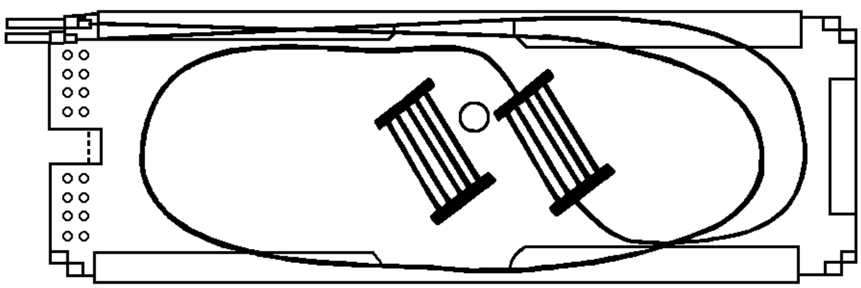
- Small fiber counts.
- Butt style.
- Smaller.
- Multiple drop ports.
- Environmentally sealed.



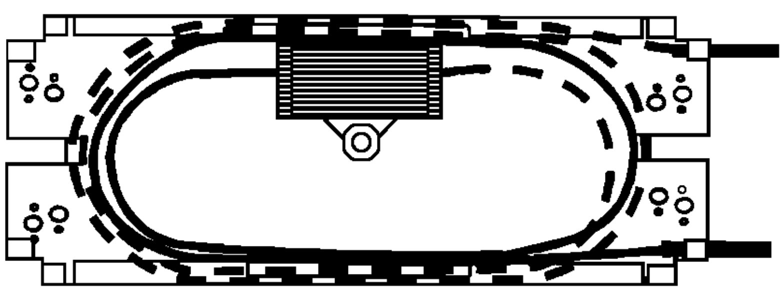
Splice Trays

Internally, splice panels normally have splice trays to organize and house either fusion or mechanical splices. All splice trays should be designed for proper bend radius for both single-mode and multimode fibers. Other additional concerns include:

- Color code organization.
- Securing the cable and buffer tube elements.
- Routing and securing the fiber, buffer tube and pigtails.
- Bonding to ground if metallic elements are present.
- Deeper trays for ribbon fibers.
- Housing splitters.



Splice tray with clear plastic cover



Splice tray for 12 fusion splices

Splice Tray Recommendations

Most fiber networks are designed for a 25-year life span. Over time, many additions, moves, and changes will occur. Normally you would want to store spare cable buffer tubes and fiber slack in the splice tray to address these future adds, moves, and changes.

Splice Trays

Most splice trays are designed to hold up to twelve fibers in a design that addresses both mechanical and optical radius concerns. This includes proper bend radius, color code organization, securing of the buffer tubes and proper labelling. Ribbon splices require deeper trays than standard types.

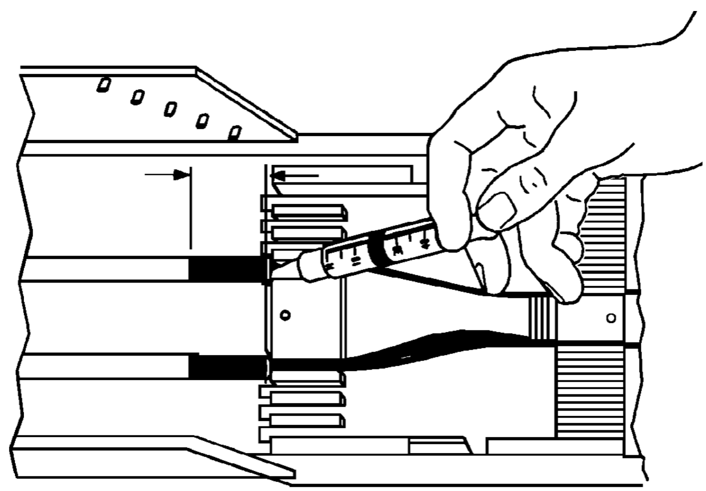
Loose Tube to Loose Tube

This structure is most common in closures where two tubes are spliced together. If the yellow tube is being spliced to a yellow tube, each containing twelve fibers, the following must be considered:

1. Securing the tubes.
2. Blocking the tubes.
3. Routing the fibers.
4. Splicing the fibers.
5. Protecting the splice.
6. Mounting the splices into holders.

Loose Tube to Pigtails

1. Securing the tube.
2. Blocking the tube.
3. Routing the fibers.
4. Labeling the pigtails.
5. Securing the pigtails.
6. Splicing the fibers.
7. Protecting the splice.
8. Mounting the splice into holders.



Blocking loose tube gel-filled cables is done to keep the gel from migrating into the splice tray, closure or patch panel.

Courtesy OFS Technologies

Notes: Remember that pigtails use 900-µm coatings and 3-mm jackets and will reduce the amount of space in the tray.

Remember that once you use all of the fiber slack, you must cut back the cable to recover more buffer tube for the splice tray.

Ribbon fibers require specific splice protectors and splice trays. They also require care in routing and slack storage. Ribbon mid-entries can be difficult and must be taken into consideration when selecting splice trays, closures, and patch panels.

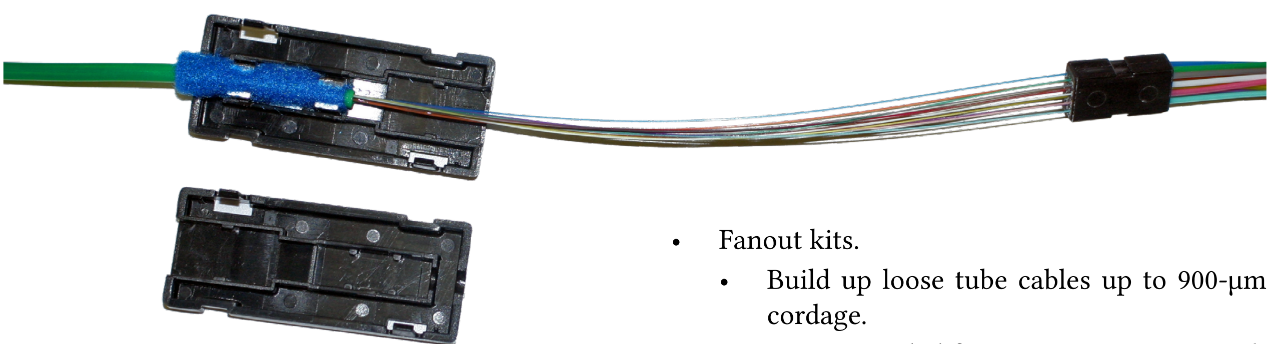
Fanout and Breakout Kits

When terminating loose tube cable into rack- or wall-mounted patch panels, it is recommended that a fan out or breakout kit be installed onto the fibers for additional physical protection.

Fanout kits are installed onto loose tube cables to build up a 250-μm fiber to the minimum size of 900 μm that is recommended for direct termination with plugs. Fan out kits should be used inside a panel, rack, or cabinet so that the cabinet supports the weight of the cable and no stress is placed on the fibers or connectors.

Breakout kits build up loose tube cables to 3-mm breakout-style cordage so that they have more durability and structural integrity. This is beneficial if they are to be installed in high-traffic areas and plugged directly into equipment.

In most cases, when terminating unitube cables, the fibers will need to be separated into smaller, more manageable groups in order to splice or terminate with plugs. This can be accomplished by using a pitchfork splitter and buffer tubing. After the fibers have been divided into smaller groups, they will resemble a stranded cable, at which point either of the two previous methods can take place.



- Fanout kits.
    - Build up loose tube cables up to 900-μm cordage.
    - Recommended for termination into patch panels when not splicing.

- Breakout kits.
    - Build up loose tube cables to 3-mm cordage.
    - Recommended for high-traffic areas.

Stranded cable breakout kit

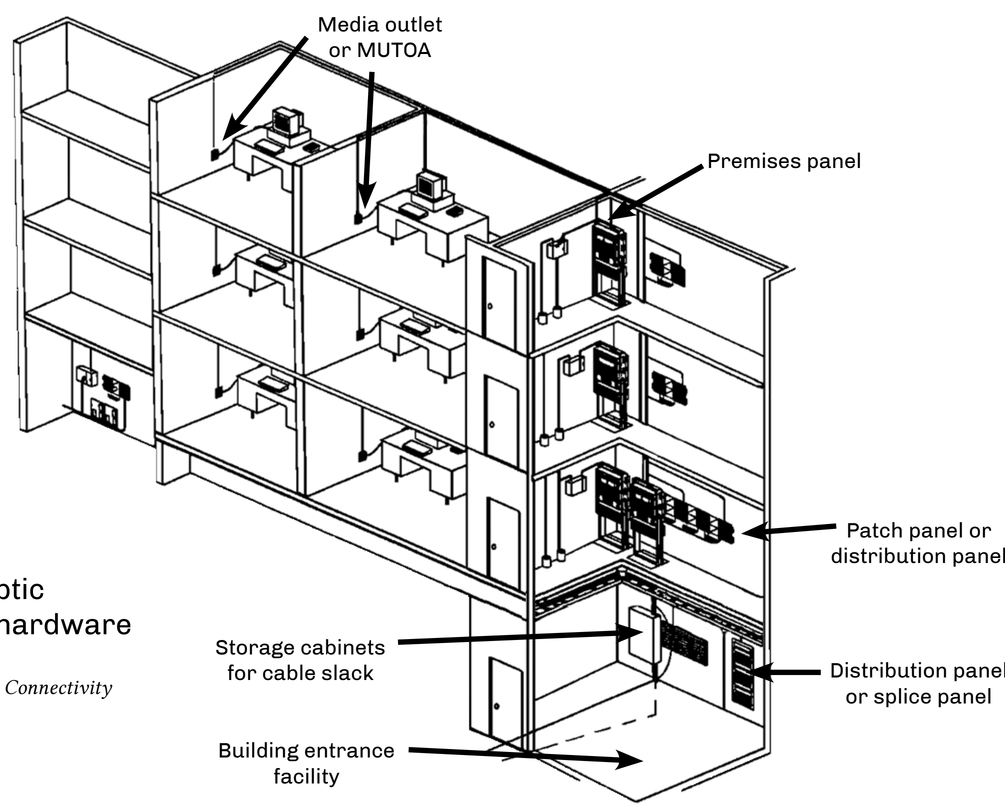
Buildings and Campuses

The term “campus” can include hospitals, airport terminals, business parks, schools, office buildings, government facilities, military bases, and factories. These can be vertical and/or horizontal structures located over large areas.

The age, structure, user density, and bandwidth requirements of the building or campus will directly influence the method of cable installation and where fiber and cable management products are placed. What type of fiber is required to support current and future bandwidth requirements of the users? What termination technique should be used? Should bend-insensitive fibers be used? Most campuses use data communications, but video services and security systems can also be a part of the requirements.

Building entrance sites and indoor and OSP transition sites need to be located, including telecom, communication, or utility closets. Where should cable and fiber management products be located within these sites and elsewhere throughout each building?

- Challenges.
  - Applicable building codes.
  - Risers.
  - Horizontal infrastructure.
  - Asbestos.
  - Firewalls.
  - Aesthetics.
  - Security.
- Types of products.
  - Patch panels.
  - MUTOAs.
  - Distribution panels.
  - Optical entrance enclosures.
  - Cable storage panels.

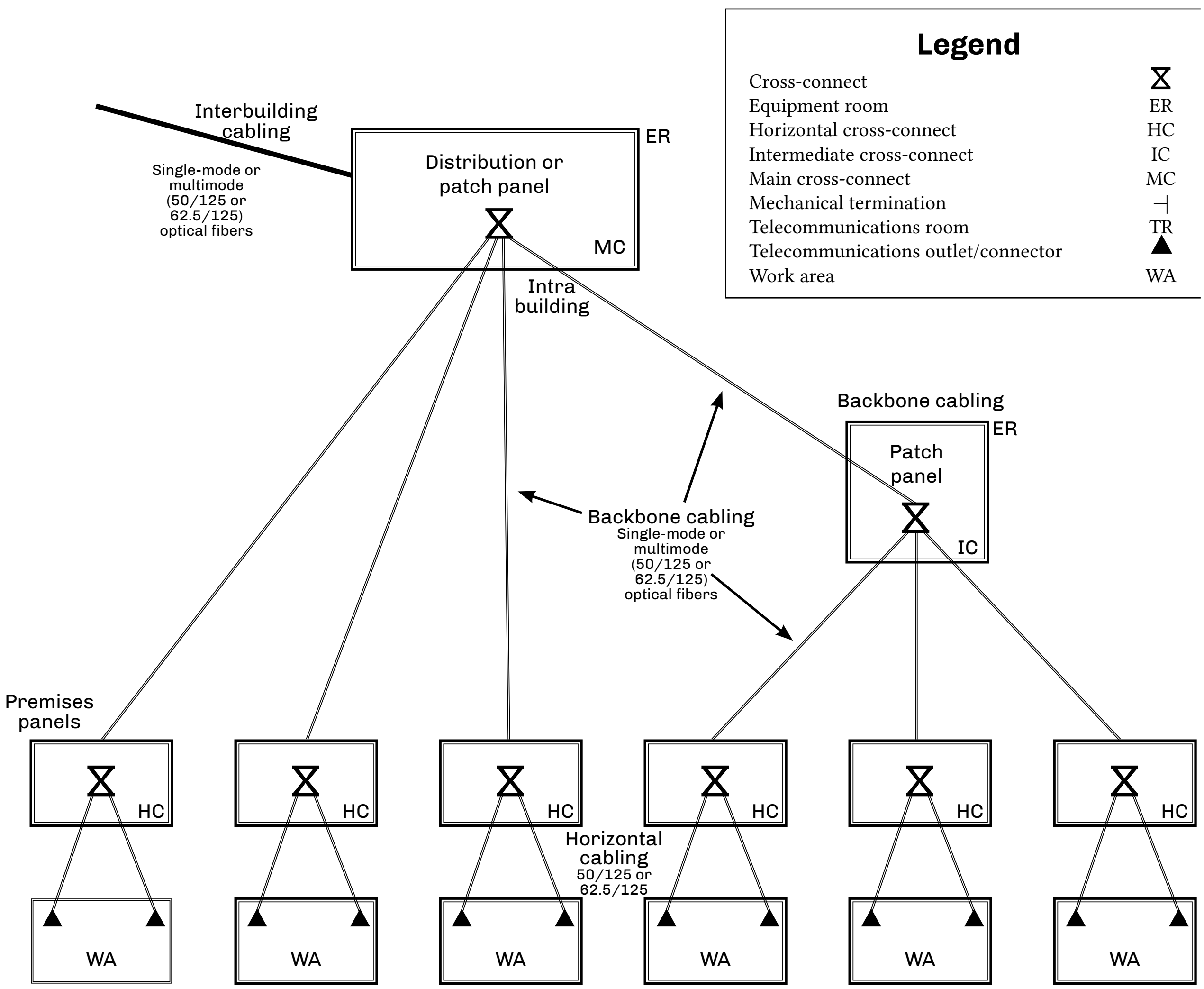


Fiber optic
interconnect hardware

Courtesy TE Connectivity

Campus or Building Star Topology

The backbone hierarchical star topology is used for campus, building, or FTTx designs. The following example shows how the cabling can be organized using a star topology and in accordance with the TIA-568 Commercial Building Telecommunications Cabling and the IEC 11801 Generic Cabling for Customer Premises standards. The span distances should be calculated for attenuation based on the distance, the number of terminations, the fiber type, and the wavelength. The fiber type, distance, and wavelength are also used to determine the bandwidth for multimode fibers, or the dispersion for single-mode fibers.



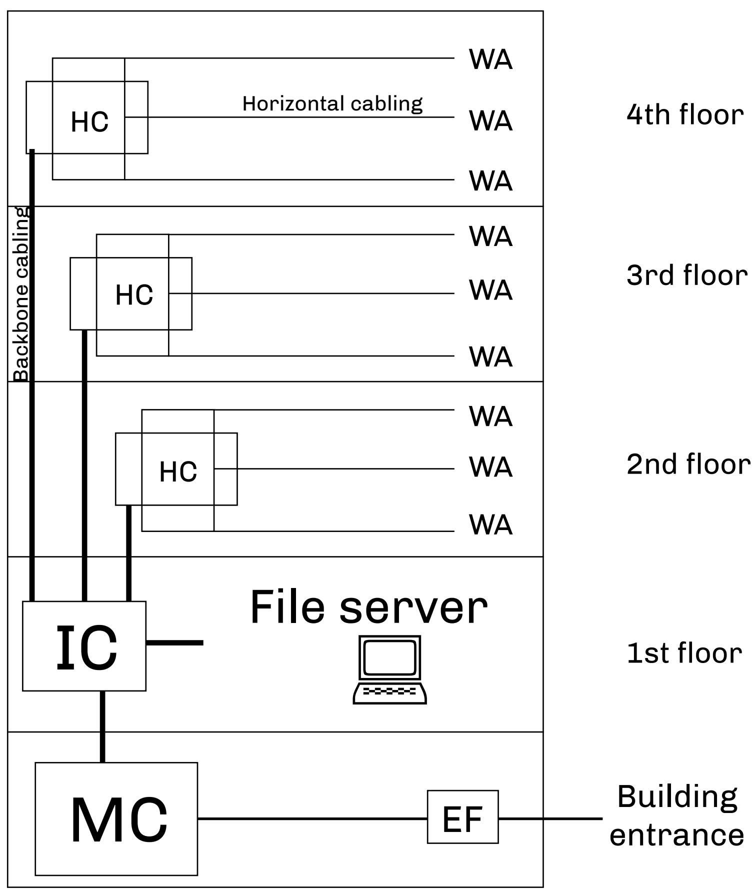
Maximum distances	Multimode	Single-mode
MC to IC	1500 meters (4,920 feet)	2500 meters (8,200 feet)
MC to HC	2000 meters (6,560 feet)	3000 meters (9,840 feet)
IC to HC	300 meters (984 feet)	500 meters (1,640 feet)
HC to WA	90 meters (295 feet)	Not recognized

Typical Building Layout

In this example, an outdoor-style loose tube cable enters the building. To meet NEC requirements, the cable must not extend for more than 50 feet (15 meters) into the building. The entrance facility (EF) may be designated as a telecommunications room (TR), telecommunications closet (TC), equipment room (ER), common equipment room (CER), or a common telecommunications room (CTR). Regardless of its designation, this is where access providers and service providers may provide equipment access and terminations.

The main cross-connect (MC) is used to cross connect the backbone cables from the entrance facility. Normally wall-mounted patch panels are used at horizontal cross connects (HCs) for connections and/or splices to the horizontal cables linking work areas (WA) and or subscriber locations in fiber to the building multidwelling units (MDU) and multitenant unit (MTU) installations.

Be sure to specify the proper listings for all indoor cables being used. OFNP or OFNR plenum- or riser-rated cables must be used inside the buildings.



TIA-568 allows 300 meters (984 feet) between the centralized cross-connect (MC or IC) and the work area (WA).

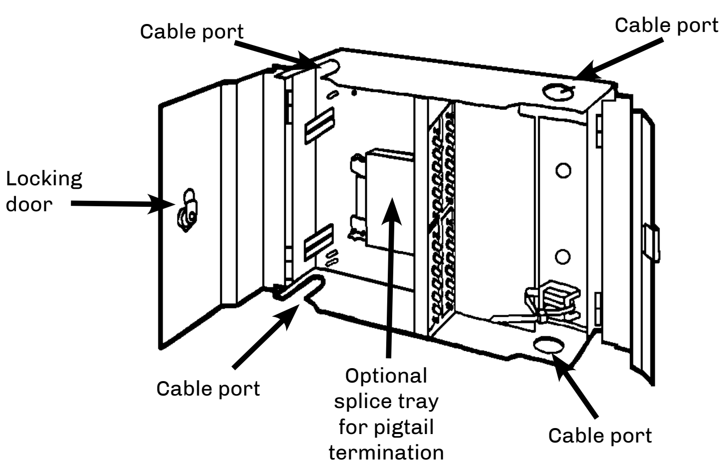
NEC Articles 250 and 800 require that all communications **systems** entering a building be bonded to the building's grounding electrode system. "Systems" includes the equipment. In the case of fiber optics cables, only those with metallic members need to be bonded to ground.

Premises Panels

Horizontal Cross-connects

Designed for applications of up to 144 fibers, the premises panel is designed for wall mounting and allows the user flexibility in cable routing, connector types, and splice methods. The unit usually has one or two latched doors with locking mechanisms, allowing the splices to be locked and all patching work done in an unlocked portion. The primary applications are intermediate (IC) and horizontal (HC) cross-connects in local area networks (LANs), but they are often used by service providers at building entrances (FTTB) with an optional splice tray for holding single-mode pigtail splices.

Wall mount distribution panel with fanouts.



Features

- Controlled bend radius
- Secured access
- Cable management
- Fiber identification
- Grounding option
- Optional connector types
- SMF or MMF.
- Optional splice trays
- Fanout kits
- Options for cable access
- Flexibility for growth
- Smooth cable ports

Fiber Raceway Systems

Fiber management systems were developed to protect the optical cables inside physical facilities where routing and protection are required. This includes areas such the central office, head-ends, customer premises, computer rooms, and data centers. They provide clearly identified cable routes while protecting the cables from bend radius and uncontrolled transition problems. They also keep cables organized while requiring less space.

Cables can include preterminated high fiber count cables meeting plenum and riser rated NEC requirements and intra-facility patchcords used to interconnect terminal equipment, optical cross connects, and building entrance cabinets. Manufacturers normally will provide a family of related products that can be integrated easily to handle vertical and horizontal needs of cable routing. Related products required for a complete family of fiber management systems including straight sections, fittings, junctions, support kits, downspouts, elbows, Ts, end caps, and crosses. The goal of each component is not only to protect the cables, but to ease installation and address physical flexibility for adds, moves, and changes.

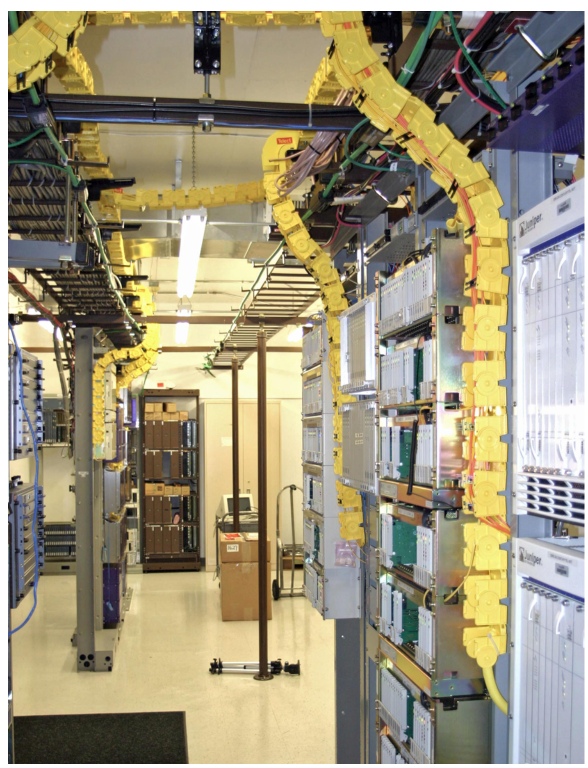
Mechanical

Fiber management products must be designed to maintain the optical fiber and cable's installed minimum bend radius specifications. They are most often found in 2", 4", and 6" variations with widths up to 24". They are designed to be mounted above racks, cabinets, and frames, as well as under raised floors where they provide better airflow for plenum areas.

Environmental

UL 94V and UL 2024 and NEC 770.51 rated and designed for Telcordia Network Equipment Building System (NEBS) general recommendations.

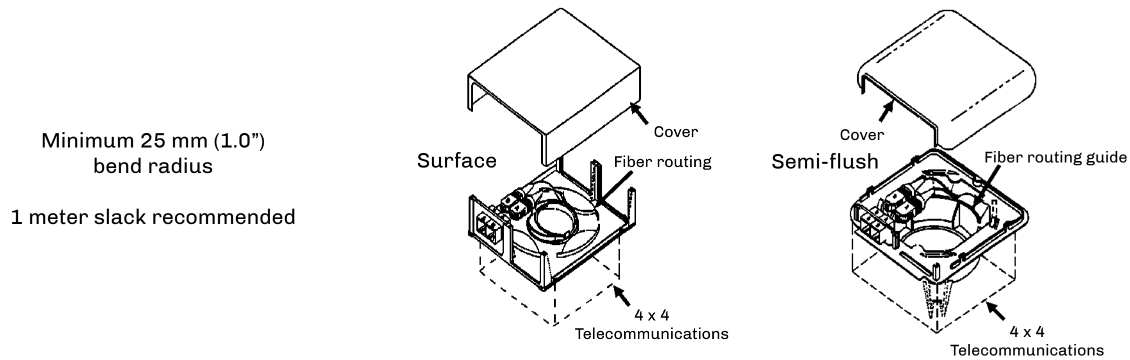
- Protects optical cable inside facilities.
- Provides clearly identified cable routing between panels and transmission equipment.
- Organizes cables while saving space.
- Easy installation of preterminated patch panels.
- Mechanical features.
- Environmental recommendations.



Work Area (WA) Media Outlets

With fiber-to-the-desk (FTTD) and fiber-to-the-building (FTTB) applications, protection, routing aesthetics, and optional interfaces are becoming more important. Two fibers are recommended along with one meter of slack at the equipment outlet.

Since most workstations generally use a mix of applications and media types, it is important to maintain flexibility in the media outlet products. For locations with multiple users, such as offices where partitions or modular furniture is used, the multi-user telecommunications outlet assembly (MUTOA) can be used. They are also known as telecommunications outlets (TOs) or equipment outlets (EOs).



Common MUTOA Interfaces

Fiber optics

SC	General purpose
ST	General purpose
LC	General purpose
MPO/MTP	

Twisted pair

RJ-11/14/45	Telephone/data
DB-25	RS-232

Coax

75Ω BNC	Video
F-type	Video

Remember:

1. Spare room for fiber storage.
2. Maintain proper bend radius.
3. Use dust caps when not in use.
4. Always angle adapters down.

Fiber to the Building Installations

Specific products and installation techniques allow for easier fiber routing within existing buildings. Design engineers have several options for termination and fiber management when considering the building layout and planning for adds, moves, and changes in the future.

Invisilight™ Solution by OFS

- 900-micron coated G.657 fibers.
- Aesthetic horizontal solution.
- Vertical integration.
- Fiber management products with slack storage.
- Multiple termination options using MPO, SC, or bare fiber.

OmniReach™ Solution by TE

- Minimizes termination costs, including MPO ribbon terminations.
- Slack storage on panel.
- Up to 432 fibers.
- Various fiber management options.
- G.657 bend-insensitive fiber and cable.

OnePass™ Solution by 3M

- Aesthetics.
- 6 or 12 fiber units.
- Hallways and inside.
- Pass through.
- No-polish connectors and terminations.

Thermal Adhesive Coated Fiber System (TACS) Solution by TE

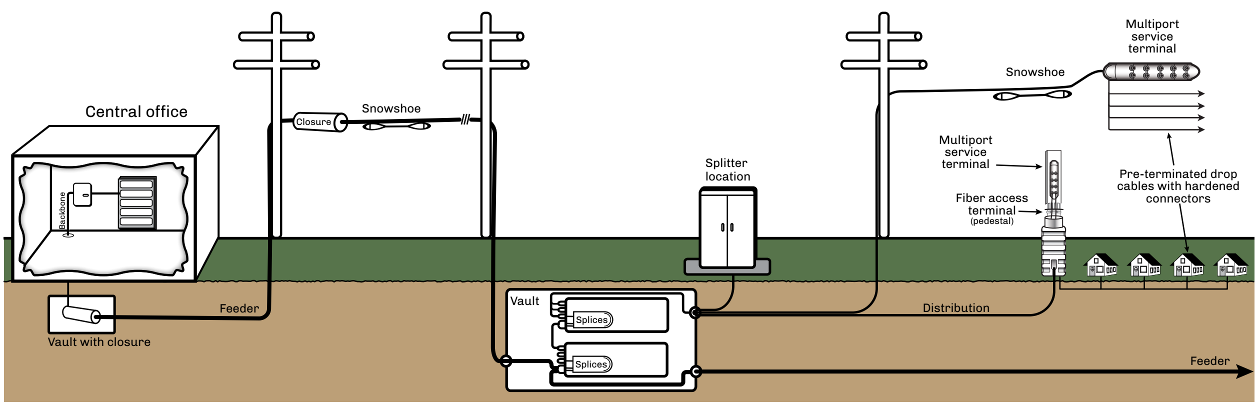
- Low profile and aesthetic.
- 900 micron G.657 fiber.
- Heat activated adhesive.
- Simple tooling.
- Easy terminations.

OSP Fiber and Cable Management

Outside plant cable management products must secure, route, and protect the optical cables as well as their internal buffer tubes and fibers. One key requirement for these products is cable and fiber management. They must control proper bend radius, be flexible, and support cable and fiber identification using color codes or numbering sequences. Other important factors include strain relief, grounding and bonding if metallic members are present, and environmental sealing with future access.

These products are designed specifically for the mechanical task they will perform.

In all fiber optic applications, the cable is placed between two sites. Therefore, some type of cable management product must be used at each end of the span, usually an indoor type of cabinet or panel. There are often splice points or mid-entries along the span, which are often enclosed in splice closures. However, other applications such as fiber to the home have high-fiber-count trunk cables for access to drop cables that provide service for subscribers. New types of fiber distribution hubs, pedestals, and closures have been specifically designed to provide fiber, cable, and circuit management while housing splices, connectors, optical splitters, and future wavelength division multiplexers.

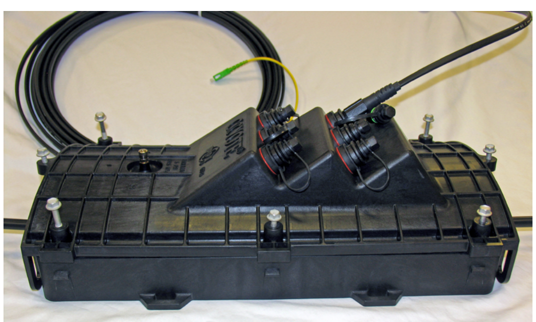


- Fiber distribution hub.
- Splice closures.
- Pedestal/FAT.
- Vaults.
- Handhole.
- Snowshoe.

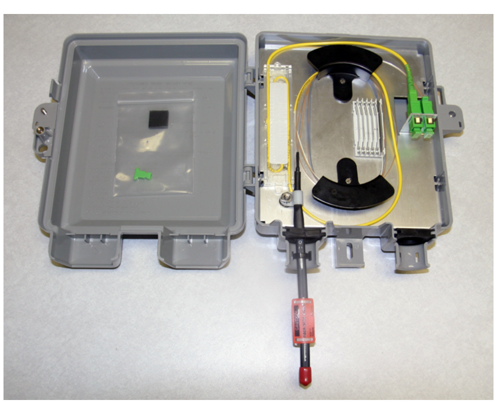
FTTx Cable Management Products

- Fiber distribution hub (FDH).
  - Houses optical splitters.
  - Splice options.
    - Preterminated with cable pigtails.
    - Traditional splice trays.
  - Connector ports.
  - Centralized and/or distributed topologies.

- Fiber access terminal (FAT).
  - Also known as a pedestal.
  - Optical splitters.
  - Connectors.
  - Slack cable storage.



- Multiport service terminal.
  - Hardened connectors.
  - Drop cable terminations.
  - Splitter options.
  - Preterminated cable stubs.



- Transition box.
  - Also known as a network interface unit.
  - Splice options.
  - Connector options.
  - Slack cable.

Outside Plant Cable Management Overview

The fiber distribution hub (FDH) addresses fiber optic cable, fiber, splitter, and circuit management for FTTx applications, as well as splicing, patching, and splitting. What makes the FDH unique is that it addresses fiber circuit management in the OSP.

The FDH can be mounted on the ground, on a pole, or in a building. It is environmentally sealed from dust, rain, wind, and rodents. The cabinets are designed to be breathable and are strictly passive cabinets.

Fiber Distribution Hub (FDH)

- Splicing, patching and splitter functions combined in the same unit.
- May contain removable trays for convenient maintenance, testing, and splicing.
- Provides physical circuit management for FTTx installations.

Splice Closures

- In-line or butt style configurations.
- Accommodate a variety of cable types, splice types and cable counts.
- Provide mechanical protection of the splice point.
- Multiport service terminals for factory terminated drop cables.

Pedestal (Fiber Access Terminal)

- Provide fiber routing, storage, patching and splicing capabilities.
- Utilized similarly to a splice closure.
- Provide an option for servicing serving areas and local neighborhoods.
- Accommodate hardened connectors in multiport service terminal (MST).

Vaults

- Can be above ground or below ground.
- Powered and conditioned for electronics, or have contain nothing but closures and cable slack.

Handhole

- Limited space.
- Require space to hold slack cable and splice closures.

Snowshoe

- For aerial installations.
- Store cable slack for future adds, moves, and changes.
- Strand storage or butt splice closure installations.

- Dual closure technique.
  - Feeder example using mid-entry to provide protection.
- Distribution splice closure to allow local access.

Fiber Distribution Hubs

The fiber distribution hub (FDH) is an outside plant cabinet designed to house fiber optic splitters with splicing and patch functions combined in the same unit. Designed for FTTx installations, the FDH allows for effective cable and fiber management, and for maximizing take rate when grouping splitters into local serving areas. The FDH is mostly used in centralized architectures, but can be used in distributed designs as well. FDHs come in many sizes and configurations with variations for pedestal, pole, or wall-mount mounting.

The FDH should be placed so that the cable is terminated or an mid-entry is performed for the buffer tube or fiber access. Fibers are then spliced to splitters and pigtails routed to an internal cross-connect (patch) panel. Drop cables to streets or homes would be internally pigtailed, spliced, and routed to corresponding ports in the patch panel for reconnection to the OLT path.

Modular connector and splitter housings can provide flexibility. The types of splitters installed can range from a small concatenation of many to the recommended maximum. The input fiber is pigtailed to an appropriate connector for loss and reflection. Each incoming fiber is terminated and routed to the input port of the splitter.

Pigtails are attached to the fiber in the customer's drop cable that is fed in and stored in the bottom of the cabinet. Once a customer has signed-up for service, a pigtail is taken from its parked position on the patch panel, routed, and then plugged into the output of the splitter module. The parked position provides cable/connector storage and termination to reduce reflection during the time the connector is not in use.

Benefits

- Splitter housings.
- Various configurations.
- Feeder to distribution fibers.
- Feeder to drop fibers.
- Cable stubs inbound and outbound.
- Growth and migration.
- Flexibility.
- Pad, pole, and wall mounting.
- Easy fiber management in the ODN.
- Splice point for drops, distribution, and feeders.
- Test access points.
- Controlled slack storage.
- Cost-effective provisioning.
- No power or HVAC requirements.
- Indoor FTTB versions available.

Courtesy TE Connectivity

Fiber Access Terminals

Pedestals

Pedestals provide fiber routing, storage, patching, splicing, and splitting capabilities. Cable storage and routing are in the base. Once the fiber from the cable is exposed, then it can be utilized to either a splice closure or cabinet. FTTH pedestals, which are also known as fiber access terminals (FATs), tend to be smaller than fiber distribution hubs (FDHs) and are an option for servicing local neighborhoods and serving areas.

When considering what type of containment will protect each component of the PON system, thought must be given to whether the assembly contains splitters, curbside electronics, battery backup, security, air conditioning, and/or alarms associated with various installation and electrical codes. These factors will determine the size and style of the enclosure assembly.

The general location of the enclosure should be out of the direct traffic pattern to help prevent accidental vehicular damage and to provide access for technicians.

Fiber access terminal

Courtesy Charles Industries

Courtesy TE Connectivity

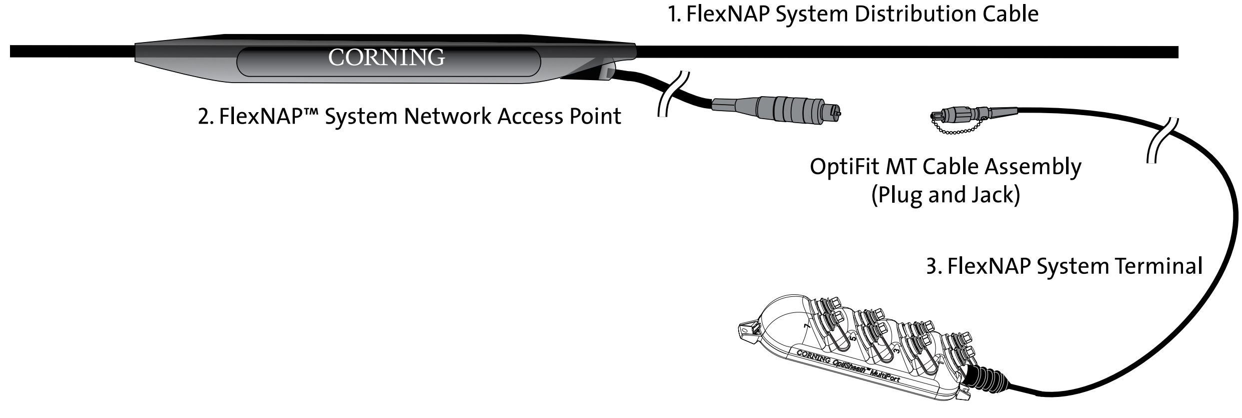
- Urban and rural applications.
- Transition for small fiber routes.
- Mid-entry capable.
- Cross-connect, splice, and splitter options.

Multiport Service Terminals

Historically as fiber gets closer to the end user, fiber count drops and construction and labor costs increase. For this reason, termination techniques have evolved to lower installation costs while still maintaining quality terminations. The multiport service terminal (MST), used for low-cost installations, is an example of this. Preterminated hardened drop cables reduce labor costs to installing the MST, accessing the fiber(s) from the distribution, and the dressing, cleaning, and connecting the drop cable. Available with port counts of 4, 6, 8, or 12, this technique can service multiple residences easily.

MSTs with splitters provide even greater options for designers. They are available for aerial and below-grade installations, and are adaptable for applications where fiber optic cables must be located in the future.

- Dress slack during installation.
- Keep ports capped when not in use.
- Clean ferrules and adapters every time the port is exposed.



Courtesy Corning

- Traditional drop cable spliced to distribution fibers.
- MST with hardened connectors.
  - Dust caps.
  - Up to 12 ports.
- Slack storage.
- Mid-entries.
- Environmental sealing.

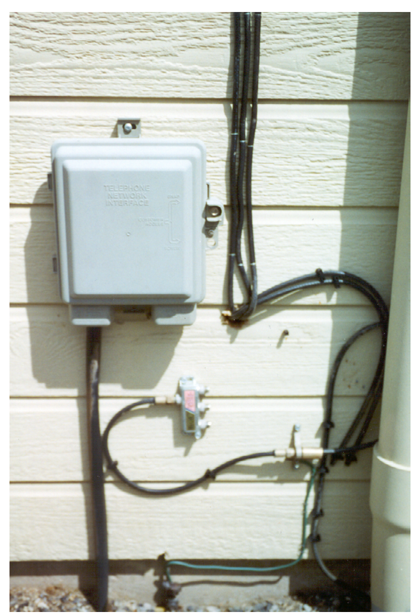
Fiber Transition Terminals

Fiber transition terminals (FTTs) offer a connector interface that gives a subscriber access to services. This unit is placed on the side of the customer's premises, usually where the optical network terminal (ONT) will be installed in the future. When the customer accepts services, a technician opens the FTT and patches the connectors so that the system will begin to supply services to the customer.

In FTTx installations, the FTT acts as a transition point during the construction phase. Drop cables can be installed and slack left until the user subscribes to services that would require an ONT. Once this occurs the FTT can serve as the splice point for the pigtail, saving valuable space in the ONT.

In FTTB applications, the FTT also acts as a small cross-connect terminal as there may be higher fiber counts, splicing needs and connector ports for cross connections. Normally these would be secured and placed at an entrance facility or telecommunications closet.

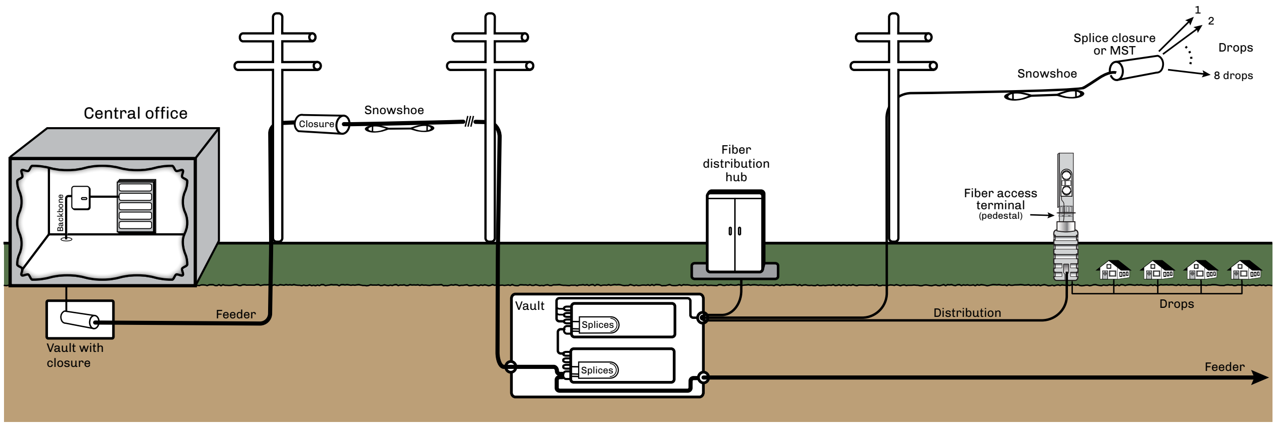
- Temporary storage.
- Low cost.
- Slack fiber storage.
- Connector options.
- Splice tray options.
- Media converter options.



Cabling Scenarios

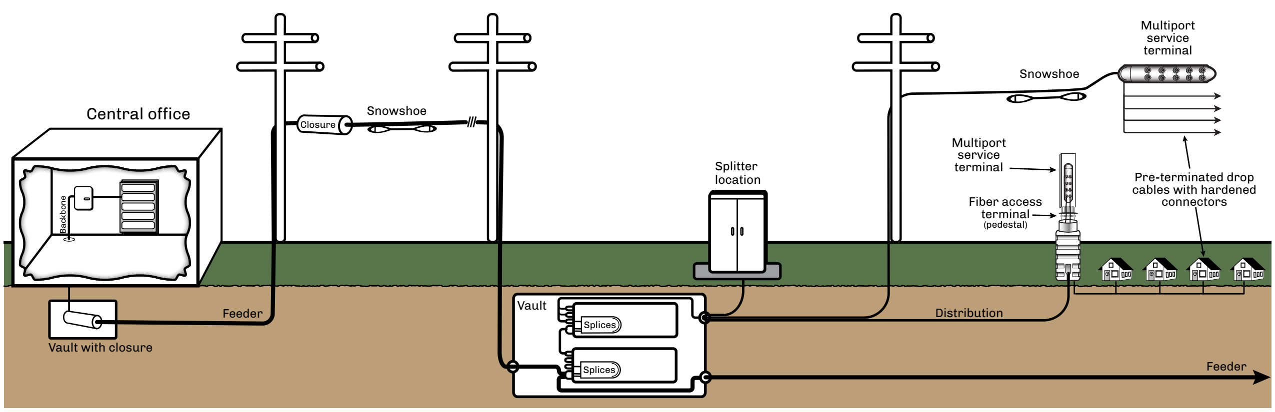
Fiber to the Home

FTTH with Conventional Drops



Designers and installers of FTTx drop cables have several options for the final terminations. The conventional technique is to install the drop cables and splice the cable into a splice closure or pedestal. A pigtail would be spliced to the drop cable at each optical network terminal (ONT) located at the home or building. Installers may choose to have long pigtails with preterminated connectors on one end. This pigtail would then be back pulled to the splice closure or pedestal where the cable slack would be trimmed as required. All the splicing and preparation work would be at one location using existing trailers, splicing vehicles and equipment. New low-cost fusion splicers, mechanical splices and field-installable single-mode connectors are options for installers for the termination at the ONT.

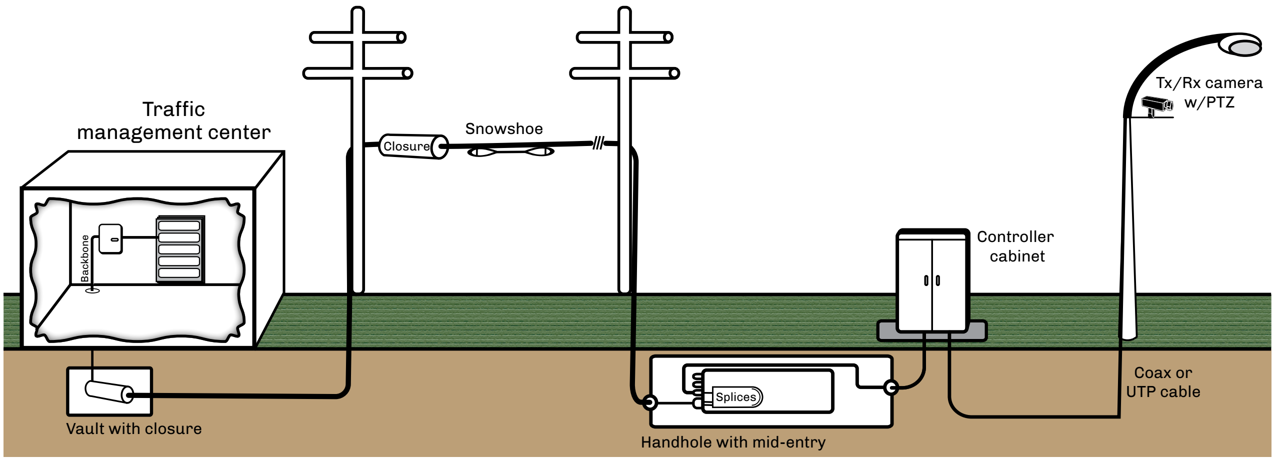
FTTH with Preterminated Drops



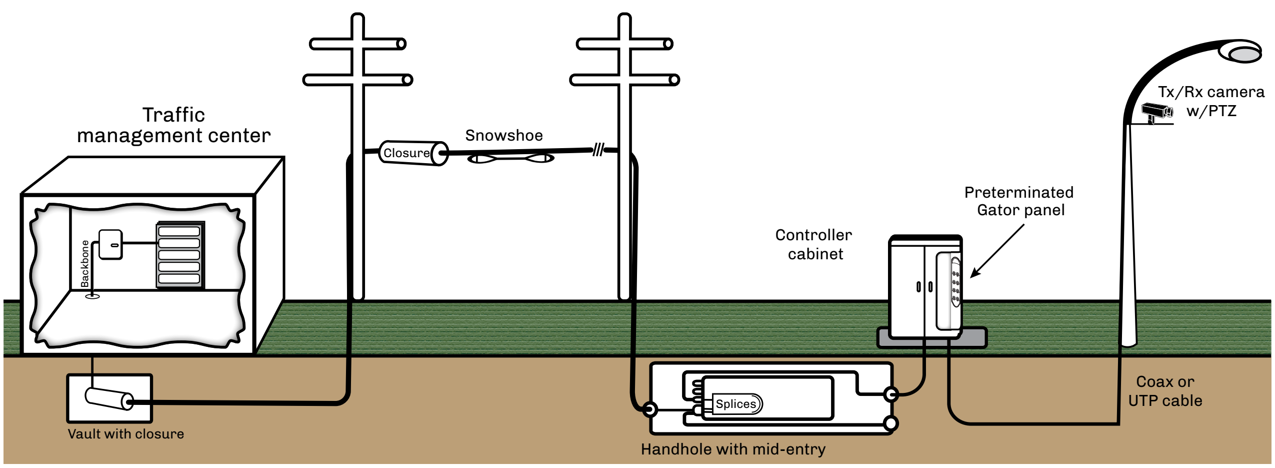
Preterminated drop cables use hardened connectors as specified by Telcordia GR-3120. The se hardened fi ber-optic connectors (HFOC) allow for low-cost installations. Th ese drops are manufactured in standard lengths. Single-ended drops can help to minimize slack challenges at the pedestal or closure where many of these cables are routed from and to consolidate the splicing at a convenient and accessible location. Th e connectors are typically a SC/APC or UPC type and have modifi ed outer coupling mechanism and dust caps. Th ese cables and connectors are also rigid with limited bend radius with most using central tube drop cable designs.

Cabling Scenarios

For Intelligent Transportation Systems



This technique involved having a splice closure in a localized handhole and a multifiber preterminated pigtail routed and spliced into the closure. The other end is routed into the cabinet to a wall mount panel (preferred) or to the specific devices to be connected (less flexibility for future adds, drops and changes). This requires a larger wall mount distribution (splice/patch) panel. PoliMod connector panels with preterminated cable stubs lowers installed cost.



In this scenario, a gator patch (manufactured by Fiber Connections) is installed into the cabinet and the other end of the pigtail is spliced to the optical cable via an end cut or mid-entry. The splice closure would be housed in a handhole or vault in close proximity to the cabinet. The gator patch is a small rectangular patch panel with preterminated plugs (and end polish, e.g., UPC or APC) and adapters per your system requirement. Patchcords are then used to connect the gator patch adapters to the various fiber-optic equipment ports.

Vaults and Handholes

Vaults can either be above ground or below ground. They can be powered and conditioned for electronics, or have nothing in them except for mounting splice closures and storing cable slack. Vaults can be as complicated with their organization so as to accommodate multiple types of cable entry or egress, or they can provide minimal slack storage depending on the need. Controlled environmental vaults (CEV) can also house electronic equipment.

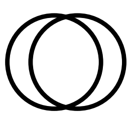
Vaults can be large and made from either concrete for maximum protection or plastic for underground burial with minimal exposure. Vaults represent security for the fiber optic installation and have become one the essential housings for FTTx systems.

Handholes are always located underground and require space to hold slack cable and splice closures.

Always make sure that the cable is within the its bend radius specifications to prevent damage and macrobend losses during storage.

Splitter locations need to accommodate splice closures, drop cable, slack storage from all locations and distribution cable slack.

Fusion splice



Spool of fiber or cable

Features

- Holds cable slack at controlled bend radius.
- Can house splice closures.
- Load bearing options.
- Protects access to ducts and innerducts.

Panel and Closure Considerations

	Topic	Things to Consider
Type and mounting style	• Distribution • Patch • Splice • Closure	• Choose wall mount or rack mount. • Choose sizes and splice/patch density to plan for future growth.
Fiber count	• Inbound • Outbound • Cross-connect	• Plan backbone fiber counts and drops for current and future needs. More fiber is a fairly low-cost addition when done in the initial order/build!
Connectors	• Adapter plates • Connector type • Attenuators	• Choose for performance as well as density needs.
Splitters	• Various split ratios	• Consider form factor and how to connect into the network.
Splices	• Trays • Splice type	• Are these separate or combined enclosures?
Mechanical	• Strain relief • Bend radius • Knock outs • Growth • Environmental sealing • Re-entry	• Good cabinets and enclosures are designed to accommodate mechanical needs. • To prevent microbends, use Velcro® tie wraps to secure patchcords, pigtails and buffer tubes.
Identification	• Fibers • Cables • Ports • Jumpers • Labels and mounting	• Use the premade labels and cards when available. • Proper labelling during installation will save time later.

Chapter 7 Review

1. What type of panel can be used as a central access location for testing and troubleshooting?

2. What does a fanout kit do?

3. What standards are used for premises installations of cable management products?

4. What cable management product has both splicing and connector functions?

5. What do break out kits do?

6. What does a splice closure do?

7. True or false: Cables should still be able to move freely when secured with tie wraps.

8. True or false: The damage that tight tie wraps can cause is not limited to breakage, most often it causes a significant reduction signal, requiring unnecessary troubleshooting and network down time.

9. True or false: When dressing in fibers into patch panels, it's very important not to leave any fibers outside of the internal cable management, as microbends can occur when fibers are compressed or pinched by panel doors, latches, or other hardware.

Chapter 7 Review

10. What must be performed if a cable has metallic elements?

11. Is strain relief a requirement for fiber and cable management products?

12. What does “RU” denote?

Chapter 8
Installation

By the end of this chapter, you will be able to:

- List and explain various methods of installing optical fiber
- List the building codes relevant to the installation of premises fiber optic cables
- Explain the difference between the terms “dynamic” and “static” in terms of bend radius and tension
- State the generally accepted dynamic bend radius of a fiber optic cable

Optical Cable Installation

Fiber optic cables have been designed for almost every type of application. Most common, however, are indoor cables (NEC), outdoor cables for aerial and underground applications (NESC), and cables for specialty applications (e.g., oceanic, mining, tactical). In each case, it is vital that the cable's jacketing is designed specifically for the application and its environment. Planners should always check that the mechanical, environmental, and performance specifications for the cable meet the requirements of its application.

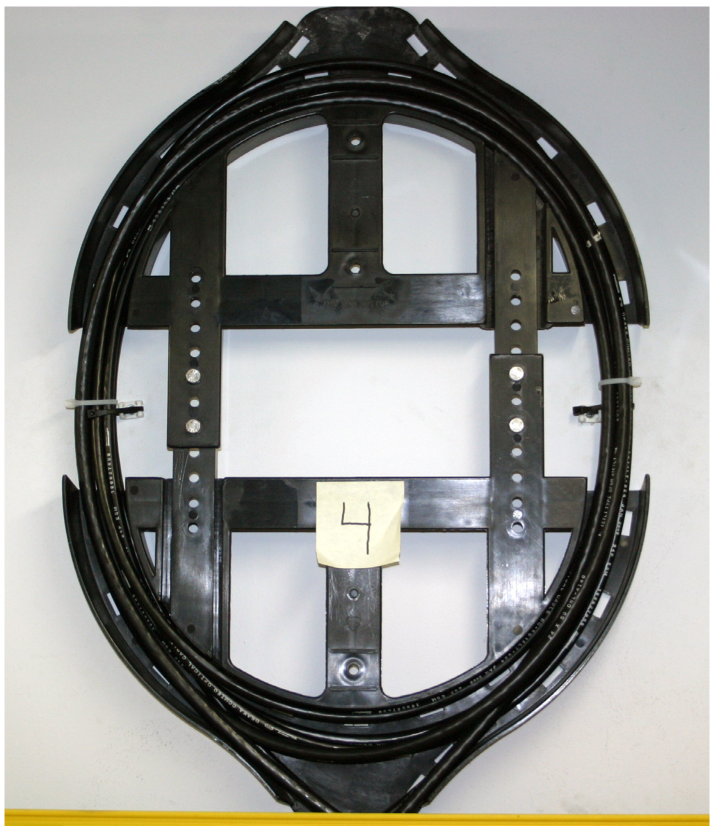
The cable's material and structure can also affect which technique is used for the installation. For example, it is difficult if not impossible to blow in armored cable using high air speed blown (HASB) technology.

Where	How	Cable Structure
Premises	**Innerduct**	Indoor/outdoor OFNR/OFNP cable Unarmored
	Cable trays Flexduct	OFNR/OFNP cable Unarmored Interlocking armor
Underground	**Buried** Direct buried Plow con	Loose tube Armored
	Pressurized High air speed blown (HASB)	Loose tube Unarmored
	Air blown fiber (ABF)	Tight buffered Unarmored
	Ducted	Unarmored
Aerial	Self-supporting Lashed	ADSS Armored/unarmored Loose tube

Cable Handling

The objective is easy installation of fiber optic cable by observing the limitations of its light weight, flexibility, and small size.

Manufacturers specify the bend radius allowed for the specific cable type and structure. Always observe the cable manufacturer's bend radius specifications. Failure to do so may result in high attenuation (macrobending) or possible damage to the cable and fiber. If the bend radius is unknown, use 20X the cable diameter, which is the industry standard.



During installation, the cable is constantly being pulled around corners while under tension. Understanding tension is key for proper installation and prevention of cable and fiber damage. The TIA-568 standard states that outside plant cables shall support a bend radius of 10X the cable O.D. when not subject to tensile load, and 20X the cable O.D. when subject to tensile loading, up to the cable's rated limit.

When reviewing tensile loads, the installer may see different terminology used. "Loaded," "dynamic," and "short term" define the tensile rating during the installation. "Unloaded," "static," and "long term" define the maximum tensile load rating recommended by the manufacturer for post installations.

For designers and planners, look for locations where bend radius must be addressed. This is often important in inside building applications due to the physical limitations of the available cable chasers, risers, and horizontal routes. Bend-insensitive fiber should be used for these applications where needed.

General Guidelines For Fiber Optic Cable Installation

For all installation methods:

- Prior to installation, confirm fiber count.
- Always follow code(s).
- Maintain recommended cable bend radius.*
- Monitor tension.**
- Always follow engineering and construction placement and route plans.
- Protect exposed cables from vehicular and public traffic.
- Maintain good communications.
- Block all loose tube cables to prevent gel migration into splice trays.
- Leave appropriate slack amounts.
- Keep documentation current and up-to-date (i.e., fiber and sequential markings).
- Use warning and identification labels.

Underground:

- Identify optical cables with markers.
- Center pull long cables.
- Install innerducts or Maxcell to maximize flexibility or future expansion options.
- Plug and seal ducts.
- Follow national installation codes and recommendations.

Buried:

- Identify cable locations with surface markers.
- Plan splice points.
- Anticipate obstructions.
- Follow national installation codes and recommendations.

Aerial:

- Use proper hardware matching cable, span, and tension requirements.
- Use correct cable jacket.
- Follow national installation codes and recommendations.
- Plan slack locations and storage methods.

In-building:

- Use cable ties carefully.
- Label cables per documentation requirements.
- Tie off every two floors (as available).
- Work from top down when possible.
- Maintain minimum bend radius.
- Ensure cable jackets meet code requirements.

---

* The appropriate values for the cable to be used may be found in the cable specifications provided by the manufacturer.
** If cable can be pulled in by hand, tension monitoring is unnecessary.

Standards, Regulations, and Codes

National Electrical Safety Code (NESC)

The NESC is issued every five years by the IEEE (standards.ieee.org/nesc) and applies to electric (power) supply and communications utilities that include, but are not limited to, telephone and broadband cable. It is the final authority on electrical and telephone construction for OSP aerial and underground applications.

It covers line equipment, work practices, construction disciplines, and standards for areas such as environmental conditions including wind, ice, lightning, corrosion and temperature. It applies to the initial design, construction, and operation including maintenance of the life of the installation. The NESC code book is not intended as a design guide. Values given are meant to be minimum values for safety reasons.

For the NESC to become a legal requirement, a state authority that has jurisdiction over utilities typically adopts it. To determine the specific legal status, the authority with jurisdiction should be contacted.

National Electrical Code (NEC)

The NEC is issued every three years by the National Fire Protection Association (www.nfpa.org) and is primarily used by the electrical building industry. While it is recognized by most cities, states, and countries as a requirement, it is, in fact, a recommendation that becomes code when specified. Local jurisdictions may supersede the NEC and therefore should be consulted to applicable specifications. Optical fibers are included in section 770.

NESC and NEC Comparison

NESC	NEC
Published by the IEEE	Published by the NFPA
The electrical code book for utilities	The electrical code book for the building industry
OSP focus	ISP focus
Used by engineers and utility linemen	Used by engineers and electricians
Administrative authority is typically the state public service commission	Administrative authority is typically a state, city, or local inspector

Note: Both the NEC and NESC require metallic elements in optical cables to be bonded to ground.

TIA-590

Th e TIA-590 "Physical Location and Protection of Below-ground Fiber Optic Cable Plant" standard specifi es depths, separation of conductors, protective measures, and recommendations and procedures for damage prevention activities on the part of excavators and facility owners.

TIA-758

The TIA-758 "Customer-Owned Outside Plant Telecommunications Cabling" standard provides requirements for the design of telecommunication pathways and spaces and the cabling installed between buildings or points in a customer owned campus environment (schools, business parks, hospitals, etc.)

Telcordia SR-1421

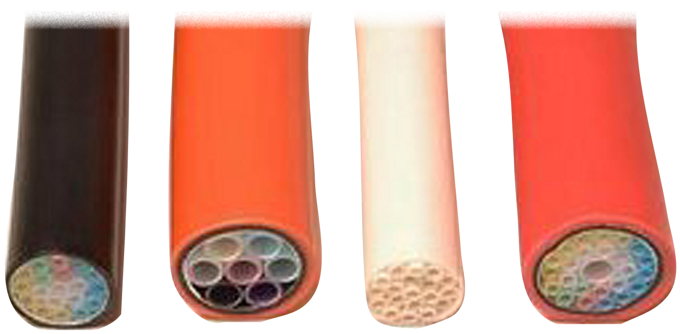
Th e Telcordia SR-1421 "Blue Book of Construction Practices" special report addresses aerial and underground installations.

Air Blown Fiber

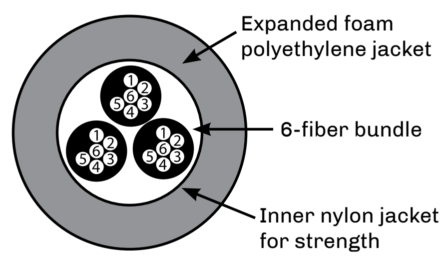
Air blown fiber is a cabling installation technique developed by British Telecom Research Labs in 1982, and now licensed by multiple manufacturers. It relies on a flow of compressed air passing over the entire length of the fiber unit or mini-cable to create a fluid drag that gently carries the cable down the tube. In addition, it is also common to have a set of rollers simultaneously push the cable into the tube.

Because the cable can be installed strain free, the amount of reinforcement once necessary to protect the cable during installation is no longer required. This allowed manufacturers to develop lower-cost cables with smaller diameters. Microduct cables are available with 96 fibers and an outside diameter of 1/4".

This reduction in cable diameter has led to a similar reduction in the diameter of the tubes into which these cables are installed. For example, a 1/4"-cable can be installed inside a conduit with a 1/2" outside diameter over distances of 6000' (1.828 meters) in a single blowing operation. These small diameter conduits can be conveniently grouped into tube bundles, which offers an economical way to install multiple conduits in the ground, compared with the traditional method of installing multiple large-diameter innerducts.



Courtesy Emtelle



Fiber unit with 18 fibers

Courtesy Sumitomo

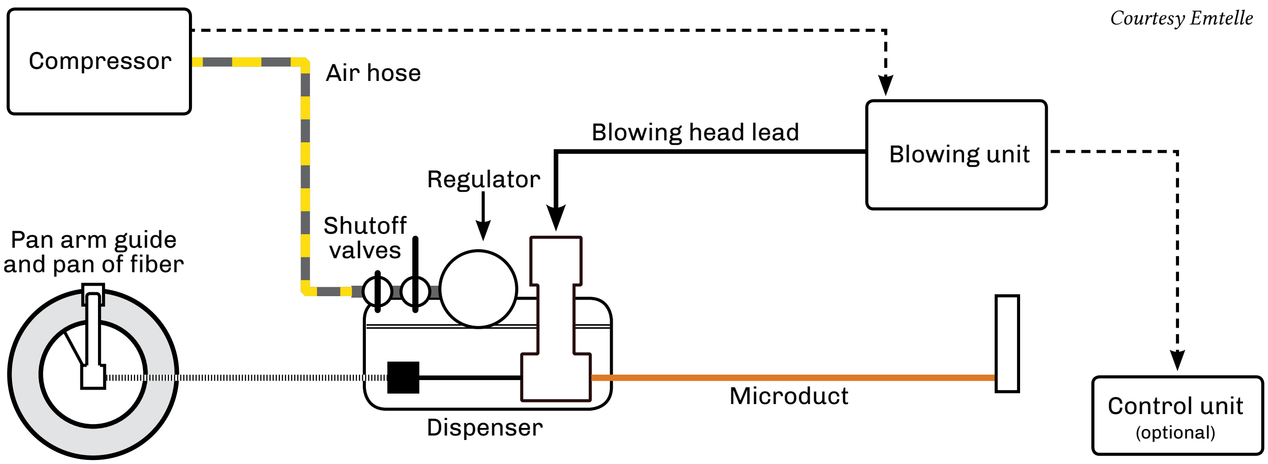
The tube bundles are suitable for installing relatively high fiber count cables in conduit, direct buried, riser, and plenum applications. A tube bundle with 24 tubes is just 1" outside diameter. Tube bundles are also available from 1/8" through 1/2" in diameter, providing the ability to quickly and economically deploy fiber optic cables

The fiber bundles are installed into the tube bundle using compressed air. The fiber bundle consists of a number of 250-µm fibers (SMF, 50/125, 62.5/125) jacketed with a polyethylene sheath. The sheath has a rough outer wall that provides a resistance to the air propelling the fiber unit through the tube bundle. Like innerduct, the tube bundle must be in place prior to the installation of the fiber unit.

As easily as the fibers can be installed, they can also be ejected from the system for quick replacement. By simply blowing in the opposite direction, the fiber bundles exit the tube bundle. This allows for "fiber on demand" installations.

Junctions are handled through branching (distribution) boxes where the tube bundles are interconnected through the use of push-fit connectors. This technique eliminates the need for additional optical splices and connectors.

Elements of an ABF Network



ABF Benefits

- **Ease of installation** — Simple techniques and equipment for the fiber unit installation. However, the pipe cable must be pre-installed by conventional techniques.
- **No tension on optical fibers** — Air pressure installation carrying the fiber units.
- **Deferred investment** — Fiber units can be added on demand to variable locations easily. Pipe cable units can be left empty until fiber units are needed.
- **Flexibility** — Fiber units can be of various fiber types (single-mode and/or multimode) and counts. Branching units with push-fit connectors allows for quick changes in network topology.
- **Cost savings** — Fewer splice and connection points are required.
- **Simple restoration** — In case of fiber damage, the fiber unit can be blown out and a new fiber unit installed quickly.

Cabling Buildings in a Star Topology

In a star topology, the cables are installed from a main cross-connect (MC) located in a telecommunications closet (TC); the TC provides access to the transmission equipment and from service providers.

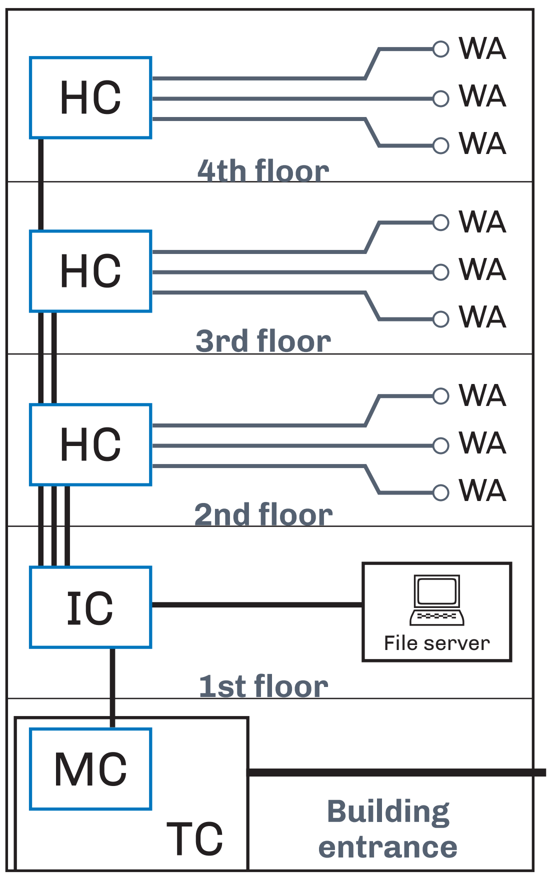
In this example, a series of 12-fiber cables are installed from the TC to a wall mounted 24-fiber patch panel at a horizontal cross-connect (HC) on each floor. From this location, drop cables or jumpers can be installed to link different users. Due to the amount of cable involved, the lower floors are more congested.

Benefits

- Simple point-to-point cable installation.
- Simple cable management.

Impacts

- Lower floors may be congested.
- No route redundancy.



- All cables installed from a main cross-connect located in a telecommunications closet.
- TC is used to access all transmission equipment and access from service providers.
- HC located on each floor.
- Drop cables or jumpers to link different users.

Cabling Buildings in a Ring Topology

Designing and performing mid-entries into cable structures provides alternate routing for building and campus networks, plus lowers attenuation and installation costs.

This example shows a mid-entry in a building. Two 48-fiber tight-buffered indoor distribution cables with four 12-fiber color-coded subunits are installed, forming a ring topology with the 12-fiber subunits terminated on each floor. The first cable is routed clockwise and the second counterclockwise. Both terminate at the intermediate cross-connect (IC) on the fourth floor. To accomplish this, the following would be required:

1. Install 24 port patch panels (HC) on each floor. On the first floor, only the blue buffer tube would be accessed and terminated at the IC on the fourth floor.
   a. Twelve fibers would terminate the fibers in the inbound blue buffer tube.
   b. The additional twelve ports would be used to terminate the 12 outbound blue buffer tube.
2. A mid-entry would be performed on each floor with only the buffer tube being accessed being opened. The orange, green and brown buffer tubes would only be accessed on the applicable floor.
3. The outbound blue tube provides another protect link from the MC from the alternate route as well as options for future growth.

Benefits

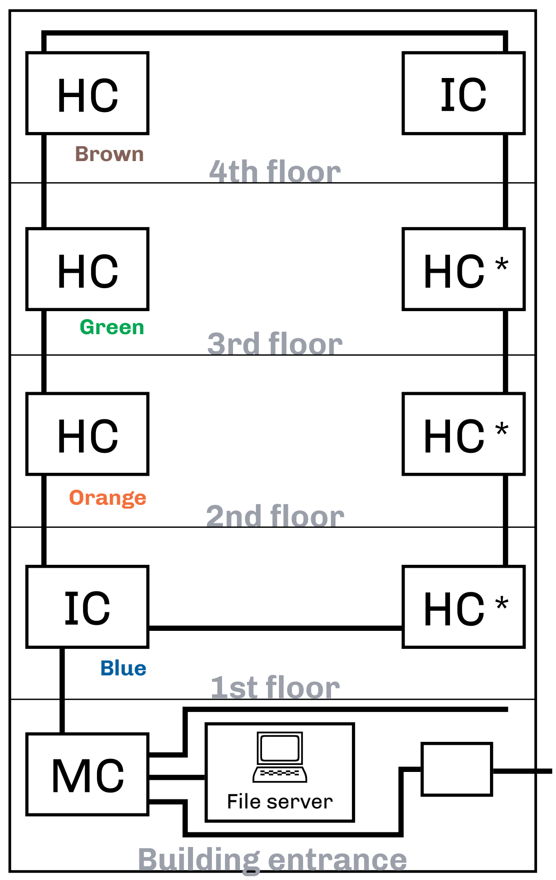
- 100% flexibility for growth.
- Route diversity and protection.
- Lower installation costs.
- Less riser space used.

Impacts

- Higher cable costs.
- Double the terminations (12 versus 24).
- Slightly larger patch panels.

Questions

1. Could this approach be used inside the building?
2. What is required at the patch panels?
3. What would be the impact?
4. What connectorization or splicing technique would be used?
5. What type of slack would be required?
6. What could be done to minimize bend radius concerns in the panels?
7. Would this save space in the risers?



*Panels are optional but provide easy future access.

Cable Trays and Cable Duct Benefits

Why Use Cable Trays and Ducts?

The main purpose of a tray system is to route cables inside buildings to their destinations and to provide support and protection. Protecting the cables helps ensure the reliability of the system. All cables have bend radius limits and the use of a cable tray system ensures that proper radius is maintained. With cable trays, it is also easier to add or remove more cables at a later date. They can also decrease installation costs with preterminated patch panels. The preterminated cable pigtail can be routed to a wall-mounted entrance splice panel. Cable tray systems offer:

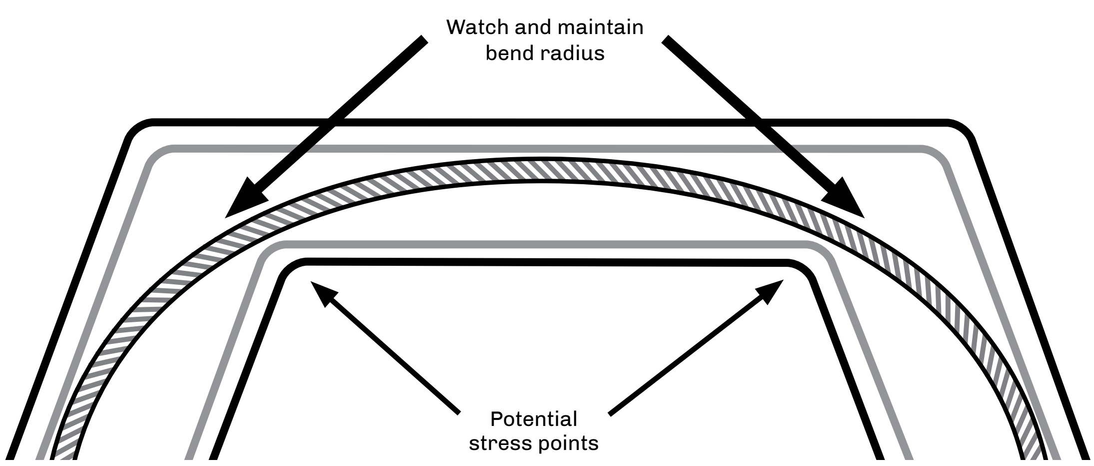
- Greater reliability for fiber optic systems.
- Better protection for the cables.
- Proper support and elevation.
- Good cable management.

Where Are They Used?

Cable trays are used widely in commercial offices, warehouses, and especially at industrial sites. They are typically found overhead in the ceiling space, or running in or along hallways. They can also be installed under the floor in large computer rooms where a raised floor system is employed.

Cable duct systems offer the same benefits as tray systems, but are typically made from a yellow plastic material and are more popular in equipment rooms and central office (CO) locations.

Specific types of cable trays include ladder, spine, and mesh styles.



An optical cable storage inside a cable tray.

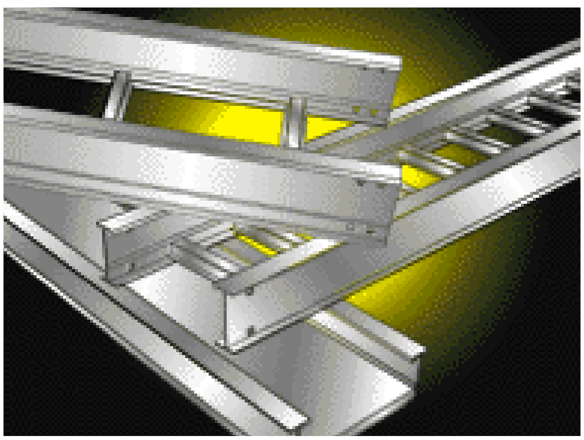
Cable Tray Types

Cable trays located above racks and cabinets are often installed into buildings to assist with the routing and protection of communication cables. Additional protection often uses interlocking armor cable, innerduct, or Maxcell. Common types of trays include ladder, spine, and mesh trays.

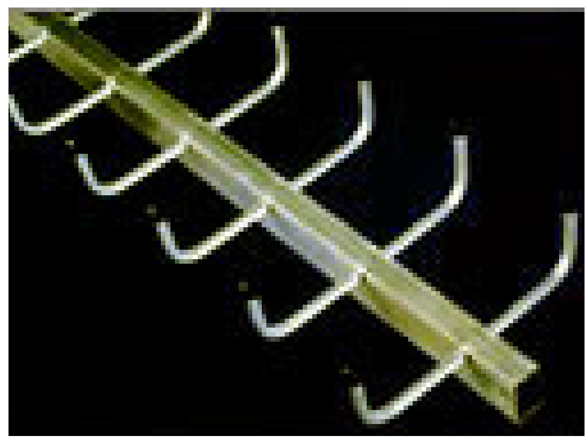
Always plan transitions, elevation changes, and corners early. The process of installing or using small sections of innerduct will provide cable protection at intersections, transition points, and elevation points.

When pulling fiber optic cable through innerduct, be sure that the duct is securely fastened to the tray and the cables secured at corners. Observe proper cable bend radius. Make sure cable ties are fastened loosely to prevent microbends in the cable.

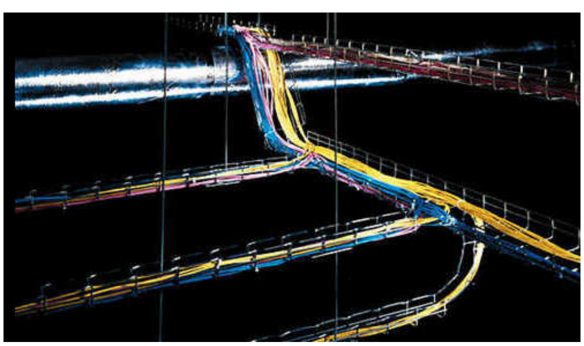
It is important to ensure that both the fiber optic cable and the innerduct meet applicable building codes.

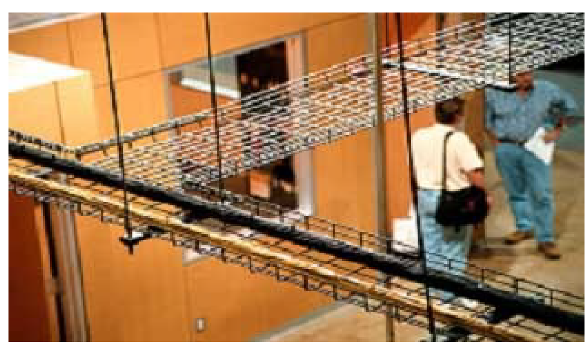


Ladder trays



Spine tray





Mesh trays

Cable Installation Products

A variety of equipment and tools are necessary when installing cable for duct or aerial applications. Some tools — such as pulling eyes and swivels — are used for both applications. Other tools and equipment may be manufactured for a specific type of installations, i.e., OPGW for utilities. The following common hardware elements are for fiber optic cable installation in aerial and ducted networks.

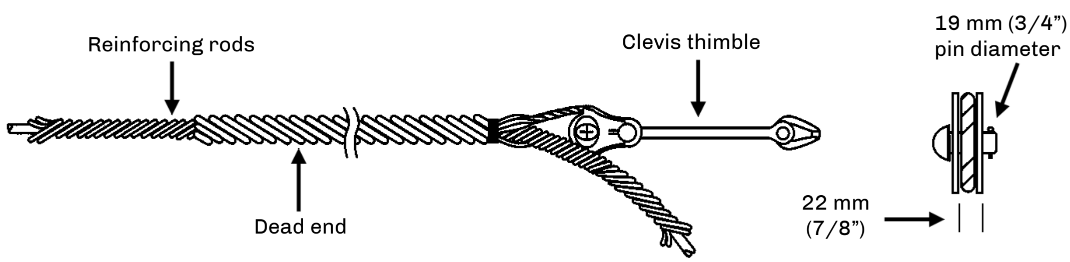
Air flow spoiler: Used to reduce galloping, thereby protecting cables and hardware.

Blowers: Several types exist, including those used for strictly air blown (HASB, ABF), tractor feed assisted, and pull assisted.

Clevis: A clevis is a U-shaped adapter that allows a swivel, pulling eye, or other apparatus to be attached via a lever, pin, or hook. Many variations exist for ducted and aerial installations, including permanent attachments, such as a Clevis thimble for pole attachments.

Dart blowers: Designed for blowing in darts up to 2,000 feet (610 meters) using compressed air at various pressures. A variety of accessories are available depending upon the application and need. Foam carriers are designed for short runs with multiple bends. Inflatable versions are made of nylon, and can expand or contract depending on the duct's inside diameter. Duct projectiles are made of rubber and used in long runs. Can be pulled back.

Dead end assembly: Secures the conductor at the pole or tower location. Size is dependent on cable O.D.



Dead end assembly

Download cushion: This device is mounted on poles and used to bring cable to splice locations.

Duct plugs: Designed to seal unused or occupied ducts from contamination, rodents, and flooding. Types available include single cable, multiple cable, single, and multiple duct. Most use compression techniques for sealing and are reusable.

Duct rodders: Ducts should be proofed prior to installation to ensure that the cables or innerducts can be successfully installed. Duct rodders are designed for strength, flexibility, fatigue resistance, and durability. Most come with attachments (e.g., harness, swivel, tapered head) and accessories (e.g., shackle head, roller guide), depending upon the application.

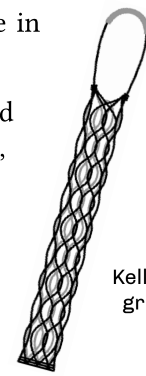
Duct swabs: Used for cleaning ducts and for spreading pulling lubricants inside ducts.

Dynamometer: A device mounted onto the pulling line allowing the operator to visually monitor the actual pulling line tension. Should the cable break, the instrument should show at what tension level the break occurred. The dynamometer should have two mechanisms for measurements. One should show the actual tension being monitored, and the second should show the highest tension monitored on the pull.

Cable Installation Products

(Continued)

Innerduct couplings: Designed to attach and seal two innerducts together. Available in internal and external versions.



Kellems grips: These are made of a wire, aramid or synthetic mesh that is placed around the cable to be installed. The grip is used to connect to the cable to be pulled into place, often in conjunction with pulling eyes, clevis, and swivels. The grip should provide a double mesh weave for positive pulling power. Also known as pulling grips.

Lashing machine: A machine that can helically wrap a lashing wire around the messenger wire and optical cable. The lashing machine can be manual or remote controlled. The cable can be mounted onto the machine or along the path of the aerial route. The lashing machine should have a friction clutch to avoid overspin in the case of sudden stops or slowdowns. The machine should be light enough to be able to be routed around obstacles easily. Remote controlled tugs may be used where access is impossible with standard methods. Water crossings, mountainous or wooded terrain would apply.

Lashing wire: The technique of lashing a cable requires a messenger 5/16" or 3/8" galvanized steel (non-electrolysis), used for supporting the cable by the use of 0.045 stainless steel lashing wire or the use of nonconductive multi-strand (70 lb. Aramid filament or monofilament) types. These types are generally much lighter and stronger than the metallic types; however, problems with clamping, stability and unraveling have occurred with their use.

Messenger wire: Used for mounting the cable to be lashed onto, the messenger gives the mechanical strength for the new cable. The messenger cable usually consists of a galvanized wire ranging from 1/4" to 9/16". Unusual loading conditions may require the use of larger messenger wires.

Phase-to-ground transition hardware: At tower or pole locations high voltage phase conductors must pass from phase to ground potential. To accomplish this, hardware designed for this may be required. This equipment should be nontracking conduit. A grounding strap and wire should be attached.

Poly line: Used to attach for blowing in projectiles and then pulling back ropes.

Pulling eyes (PVC and PE): Consisting of a pulling eye and eye sleeves, these devices are designed to screw into ducts and innerducts to assist with pulling. The eye sleeves are placed on the outside of the duct/innerduct, versus inside for the pulling eye. Variations include with swivel or clevis; also available in crimp-on style.

Pulling harnesses: Designed to attach to clevis attachments and pulling eyes, the harnesses are available at various counts and with staggered lengths to prevent the units from bunching.

Pulling rope: Made of polypropylene, a general-purpose rope designed for pulling in cables by hand. Used in the pulling process with lashing machines and innerduct installations. The rope or pulling tape used should exceed the maximum strength of the cable.

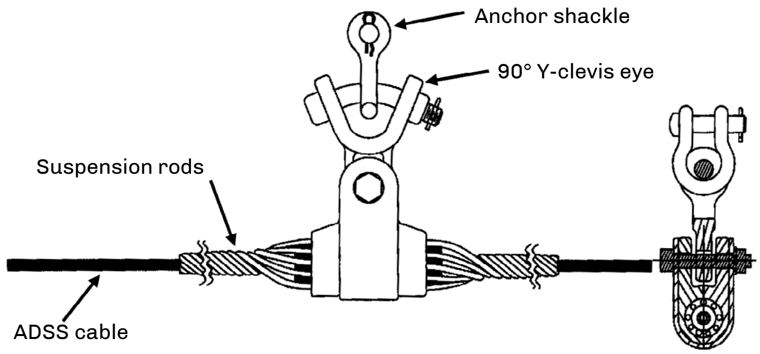
Pulling tape: A flat woven alternative to pulling rope for use with hand or machine pulling. There are versions made of polyester that are designed for pulling in optical cables and also feature sequential markings to assist in distance measurements. Also known as measuring tape.

Rollers: Hung periodically along the messenger wire to allow the cable to be routed properly.

Cable Installation Products
(Continued)

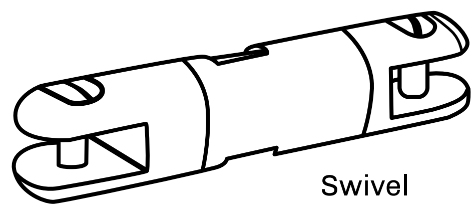
Slug: Designed for spreading pulling lubricants in tight radius turns.

Suspension clamp: Used for support and protection of overhead cables. It is designed to reduce static and dynamic stresses at the support point. The cable is clamped in an elastomeric insert and then clamped to the cable.



Suspension clamp

Swivels: Eliminate winding and tangling of cables during installations. Breakaway swivels are designed to break when the tension strength exceeds the rating. The breakaway is actually a replaceable pin. These swivels are available with different breaking tensions. Match to the cable manufacturer's "under load" tension rating. Breakaway swivels are not used in aerial plant.


Swivel

Tug: Used for pulling the lashing machine along the cable or messenger wire. Remote controlled tugs are available for use in inaccessible areas such as gorges, wooded terrain, mountainous and water crossings.

Vibration suppressors: Because of the light weight of the optical cable, vibration suppressors may be required to dampen the wind, ice or snow induced effects. Can be dependent on terrain.

Winch line blowers: Designed for blowing winch line up to 1600 feet (500 meters) into a duct, eliminating the step of blowing in a pull string and backpulling in a line. Using compressed air, the blowers also have a variety of accessories to accommodate various duct sizes and applications.

Chapter 8 Review

1. True or false: Installers must consider building codes when installing premises fiber optic cables.

2. What does the acronym NEC signify?

3. How often is the NEC reissued?

4. What is the difference between the terms “dynamic” and “static” in terms of bend radius and tension?

5. What is the generally accepted dynamic bend radius of a fiber optic cable?

6. Which type of premises cable installation uses compressed air to reduce tension on the cable?

7. What is the diameter of the fiber used in an air blown fiber installation?

8. What is the role of a Kellems grip?

9. True or false: Break away swivels will prevent excessive pull tension if the proper rated device is used.

10. True or false: Utilization of duct plugs will prevent not only moisture but also blockage.

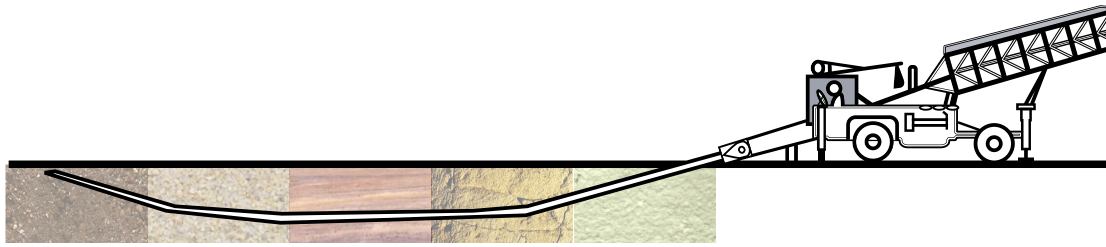
Chapter 9

OSP Installation

By the end of this chapter, you will be able to:

- List the primary methods for underground installation of fiber optic cable
- List the primary methods for aerial installation of fiber optic cable
- Describe the relationship between span length and sag
- Explain the purpose and importance of slack storage
- Explain the purpose and importance of sequential markings

Underground Installation Techniques



1. **Trenching.**
   - Concrete encasement.
   - Duct/innerduct.
2. **Boring.**
   - Duct/innerduct.
3. **Plowing.**
   - Pressurized cable installation.
     - High air speed blown.
   - Duct/innerduct.
   - Plowcon.

Above-ground Markers

Permanent above-ground markers should be placed at line-of-sight intervals to make the cable route clearly visible. Each marker should be visible from each adjacent marker but separated by no more than 300 meters (1,000 feet). Markers are usually placed at right-of-way boundaries and at locations of public access to the cable right-of-way such as utility or vehicular crossings.

Remember!
Call to locate underground utilities.

Damage Prevention Laws

Most states have damage prevention laws intended to promote safe work conditions and reduce the possibility of cable damage. These laws include the responsibilities of excavators and the facility owners.

In 2005, the FCC approved 811 as a national “call before you dig” hotline. Calling the number will connect you with one of 62 national call centers, which will request the location of your intended work site and direct that information to affected local utility companies. Within a few days, a locator from the utility will visit your job site and mark the location of any underground utility lines, free of charge. For more information, visit www.call811.com or www.commongroundalliance.com.

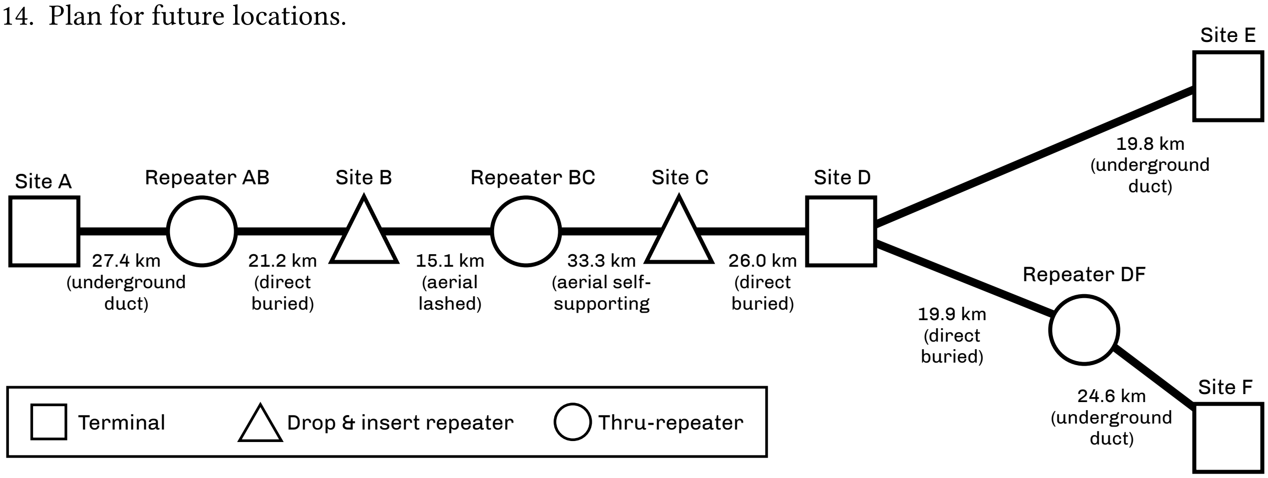
811® Know what's below. Call before you dig.

Proper Route Planning and Engineering

Provided by the outside plant engineer and construction supervisor, the route survey involves the planning and preparation required for a smooth installation.

Route Survey

1. What are the environmental issues?
2. Designate points of access for right-of-ways (ROW).
3. Identify all conflicts and obstructions.
4. Identify power requirements for repeaters.
5. Identify installation location and method.
6. Identify repeater locations.
7. Are seasonal considerations involved?
8. Will sub-surface investigation be necessary?
9. Designate construction methods suitable for soil conditions.
10. Designate the depth of burial.
11. Identify cable structure (use of Plowcon or direct buried with armored cable).
12. Identify splice locations.
13. Develop a placement plan for cable reels.
14. Plan for future locations.



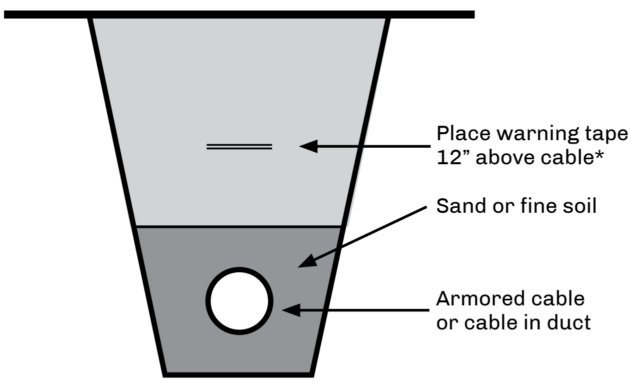
Key long term requirements when planning an installation:

- Environmental impact statements and permits will require months to years and must be addressed early in the design and planning stages.
- Right of ways (R.O.W.) and physical access for the installation and future maintenance should be considered along with any land purchase or easements.
- Scheduling the installation can also be determined by weather conditions and special regional events that will effect traffic conditions.

Cable Trenching

One method to to install fiber optic cable underground is through trenching. Trenches can be dug either manually or with a machine. While trenching is slower than plowing, it allows for a more controlled cable installation, during which the possibility of damage to the cables is minimized.

When dug, the trenches should be kept as straight as possible and the bottoms should remain level. Backfill can be used to even out the cable load. However, rocks should be removed prior to backfilling. Where the ground has little soil, a select fill should be added to protect the cable from large or sharp rocks. The use of plowable conduit adds additional protection.



Encasement

Another method to install and protect fiber optic cable in trenches is by encasing armored cable or cable duct inside concrete. The cement is laid into the bottom of the trench and the cable is placed on top and then covered again with cement. This method offers extra physical protection from backhoes and augurs, but is more expensive than conventional cable placing techniques.

Duct, Innerduct, and Maxcell

Underground fiber installations often are accomplished using ducts, innerducts or microducts. Not only do these protect the cable and simplify future expansions, their interiors are usually corrugated to ease pulling tension on the cable. They can be purchased with pulling tape or lubricant already inside, which can significantly decrease installation time. Maxcell is a multicell flexible innerduct that can increase utilization of innerduct space.

Just as with fiber, there is a minimum bend radius that must be observed during installation.

* Warning tape should not deviate more than ±18 inches (450 mm) from the center line of the optical cable (TIA/EIA-590). Tape should be orange and at least 2" wide.

Direct Buried

Proper route planning and engineering.

Equipment requirements.

Installation techniques.

The successful installation of direct buried fiber optic cable depends upon the attention to details of planning and engineering the route properly. The ability of construction crews to compensate in the field for faulty engineering or inadequate preparation is severely limited. With proper time and organization, the installation of fiber optic cables should be uneventful.

TIA-590 "Standard for Physical Location and Protection of Below-ground Fiber Optic Cable Plant" recommends permanent above-ground markers every 305 meters (1,000 feet) and/or warning tape 12" above the cable.

Depth of Burial

Facility	Minimum cover
Toll, trunk cable	750 mm (30")
Feeder, distribution cable	600 mm (24")
Service/drop lines	450 mm (18")
Underground conduit*	750 mm (30")

Separations from Foreign Structures**

- Electric light, power, or other conduits:
  - 75 mm (3") of concrete.
  - 100 mm (4") of masonry.
  - 300 mm (12") of earth.
- Other foreign services: gas, water, oil, etc.:
  - 300 mm (12") from transmission pipelines
  - 150 mm (6") from local distribution pipelines

* Multiple-duct conduit underground, with manhole access. For other duct applications, depth requirements for buried plant shall apply.
** Unless greater separations are required by state or local regulations.

Plowing

- Trenchless.
- Duct is installed underground.
- The fiber cable can be installed during plowing, or at a later time.
- Fast and easy, with little post-installation work.
- High potential for cable damage.
- Use conduit to protect cable.

The Charles Machine Works, Inc.

Direct plowing is a trenchless installation method in which tractors (or plows) are used to rip the ground and install a duct in which fiber cable can be installed. The duct may have the fiber optic cable pre-installed, or the cable may be installed at a later time using standard pulling or high air speed blown (HASB) technologies. In some cases, an armored optical cable is directly plowed into the ground with warning tape placed above it.

While direct plowing is fast, easy, and requires a minimum of post-installation work such as backfilling, cable tension is a concern and there is greater potential for cable damage.

As the cable and its underground placement cannot be seen during the installation process, it is advised that conduit be used in order increase the chances of success.

As with all underground installations, utility lines or other installations must be located beforehand and the cable must be routed around these points. Installation also is limited to areas that are free of miscellaneous objects such as rocks or debris. Pre-ripping is recommended as this technique breaks up the soil and can also identify obstructions prior to installation of the cable or duct.

In the case of PlowCon, the cable is slit open and installed simultaneously.

Vibratory Plowing

Vibratory plowing is very similar to direct plowing, except that cable from the payout reel is fed into a chute attached to a vibrating plow. The plow can be either isolated from the blade, reducing the amount of vibrations on the cable, or fixed, in which both the plow and chute vibrate.

Directional Boring

- Trenchless method.
- Installation performed through a combination of tunneling, drilling, or ramming.
    - Minimal excavation.
- Commonly used where other methods would be cost-inhibitive.
    - Near road crossings, railroad tracks, or waterways.
- Bore pits required at both ends.
    - Bore pits are a cause of cable cuts.
- The bore can be guided or steered.

Boring, or horizontal directional drilling (HDD), is a trenchless method in which the installation is performed through a combination of tunneling, drilling, or ramming with a minimal amount of excavation, environmental disruption and minimal repair to roads and driveways. This method is commonly used in areas where other installation methods would be cost-inhibitive, such as near road crossings, railroad tracks, or waterways.

After determining length, depth, and diameter, the process requires that bore pits be dug at the start of end of installation. It is critical to do accurate locates for bore pit, as these sites are normally where underground utilities are located. The size of the bore pit depends on the depth of burial and the amount of equipment needed. Shallow boring, used for FTTH installations, only requires that the cable be installed at 18” depth (per the NEC and NESC), whereas most underground installations are 36 inches or greater.

During the boring process, a pilot hole is drilled to the desired location. Locating equipment is used to guide the drill head to the required location and to monitor the depth. The pilot hole is enlarged using a reamer until it reaches the desired size. The reamer is attached to the pipe and the final duct or pipe is attached and installed, as well as any necessary vaults or hand holes. The assembly is then pulled back toward the starting bore pit and the cable is installed.

Common Boring Methods

- Pressurized water-assisted drilling heads.
- Replacement of older installations by pipe ramming, using pneumatics to ram newer pipe through, bursting the old pipe in the process.
- HDD uses lightweight, steerable equipment to perform near-horizontal utility installations.
- Stitch boring uses pneumatic piercing tools that are propelled forward with compressed air to create a small tunnel.

Equipment Requirements

1. Standard plowing equipment is generally suitable. However, modifications may be required to conform to the cable manufacturer's bend radius specifications.
2. The equipment used must be large enough to perform the job.
3. A dynamometer should be used for measuring cable tension.
4. Cable feed systems — typically consisting of a reel carrier, rollers, or guide tubes, and a cable chute — must allow the cable to be placed while following the cable manufacturer's product specifications for tension and minimum bend radius. The cable chute should have a removable gate to allow the cable to be inserted or removed at intermediate points.
5. The reel carrier should accommodate one or more reels of adequate size and should insure easy and safe loading and unloading.
6. Vibratory plows can also be used. It is best to use a configuration that isolates the feed chute from the vibration of the plow share.
7. The maximum tension developed in a cable is directly proportional to the reel weight and occurs in situations that cause the reel to accelerate rapidly. These situations usually occur during startup speed changes, grade changes, and unexpected obstacles.
8. When starting or finishing, a pit should be dug at each splice location. Sufficient cable (10+ meters) should be available to allow the splicers to work in splicing vehicles or tents. The excess cable should be coiled, secured, and buried with the spliced closure.
9. An alternative is to have the splices in a surface closure or cross-connect box. In this method splices are easily accessible. A surplus length of cable is still recommended for working in splicing vehicles.

Conduit and Duct Installation

Planning

- Calculate pulling tensions (expected pounds versus maximum cable rating).
  - Length of continuous pull.
  - Lubricant usage.
  - Cable sheath material.
  - Duct size.
  - Determine whether innerduct, micro duct, or Maxcell will be installed.
- For long lengths, use center pull methods.
  - Long pulls are desirable.
- Minimize pulls through elbows. A 90° elbow is equivalent to 200 meters (656 feet) of straight pulling.
- Don’t force cable around sharp corners.
- Don’t wrap cable around hands or wrist during handling.

Cable Duct Installation Procedures

Fiber optic cables are usually pulled into 1” to 1-1/4” innerducts that have been placed into a 3” or 4” duct underground. The innerducts can be placed in lengths of up to 2 km and continue unbroken through several manholes or vaults. Long pulling lengths are desirable to eliminate the added attenuation caused by splicing. Longer pulling lengths are made possible by the small size and lighter weight of optical cables.

Microducts are small HDPE ducts that are designed to be placed in new or existing 3/4”– 2” ducts to be utilized by microcables. Duct sizes vary from 2.1 mm to 16 mm inside diameter and come with low-friction lining. They can be installed via jetting/blowing or pulling. The microcables can be installed using the same methods. Micro ducts come in a wide range of configurations, such as grouped, self-supporting, or locatable.

Maxcell is a flexible textile innerduct that ranges from 1 to 4 inches in diameter with an interior comprised of 1-3 distinct cells. The Maxcell conforms to the shape of the cable being pulled, allowing multiple cables to be placed into a single duct to maximize available space. It is prelubricated, easy to place, and can increase usable conduit space by 300%. A 5,300’ Maxcell reel weighing 250 pounds is equivalent to three separate innerduct reels weighing 3,000 pounds. Maxcell is offered in a variety of widths and reel put-ups and is available as nondetectable or detectable, as well as in plenum or riser versions for inside buildings.

Remember:

- The NEC specifies a maximum fill ratio of 53%.
- Seal all ducts with duct plugs.
- Order ducts and innerducts with pulling line pre-installed.
- Innerduct stretches under tension.

Microducts for Fiber Optic Cables

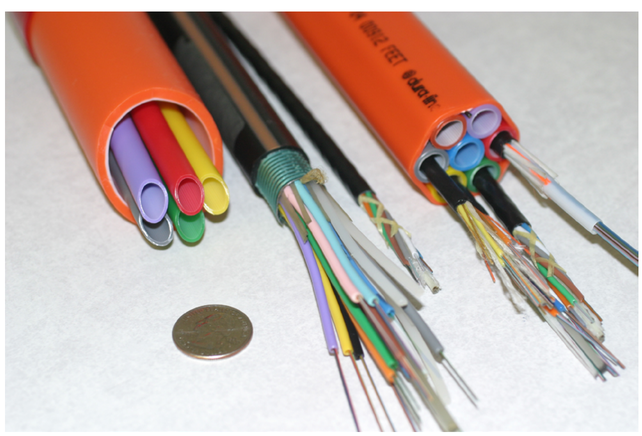
Microducts are small HDPE ducts, up to 16 mm in diameter, that can be installed into empty or partially-occupied ducts. They feature sequential markings on the outside and can be armored to provide greater rodent protection and ruggedness. They are available in stranded and unitube designs to offer flexibility to planners and users. They are designed to accommodate single microduct cables containing up to 432 optical fibers. The cable can be blown into the microduct or pulled in using conventional techniques.

Microducts are used in both the inside and outside plant portions of the network. There are locatable versions for direct buried installations such as FTTx, and plenum and riser styles for multiple dwelling unit installations. An aerial drop version that features a built-in messenger is also available.

A wide variety of accessories are available for use with microducts:

- Microduct couplers for splicing sections together.
- End caps for sealing used microducts.
- Pulling lines and harnesses.
- Mounting hardware.
- Sealing kits.
- Installation and preparation tools (straight and round cutters).
- Branching units and reduction couplers.
- Innerduct eyes, which increase efficiency during pulling installation.
- Shuttles are available in different configurations for the installation of pulling tapes and ropes.

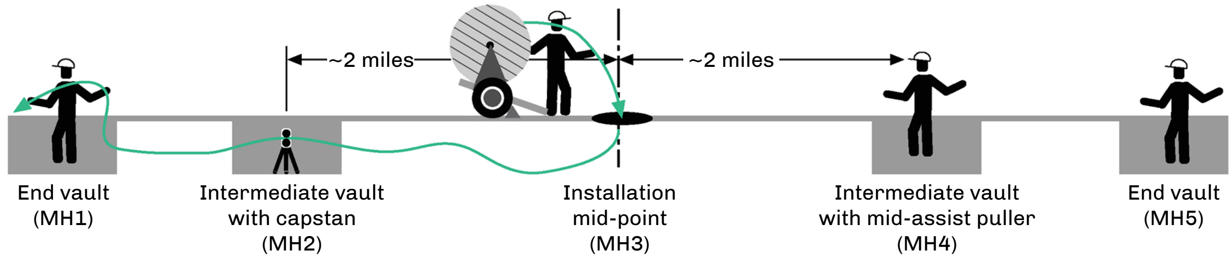
Typically, a microduct's bend radius is 20 times outside diameter (OD) during installation and 10 times OD during operation. Tensile ratings vary, from 300 pounds and upwards depending on the size, structure, and manufacturer.



- Small ducts that can be installed inside empty or partially-occupied ducts.
- Can contain up to 432 optical fibers.
- Can be armored for greater rodent protection and ruggedness.
- Stranded and unitube microduct cable designs.
- 300-pound maximum installation tension.

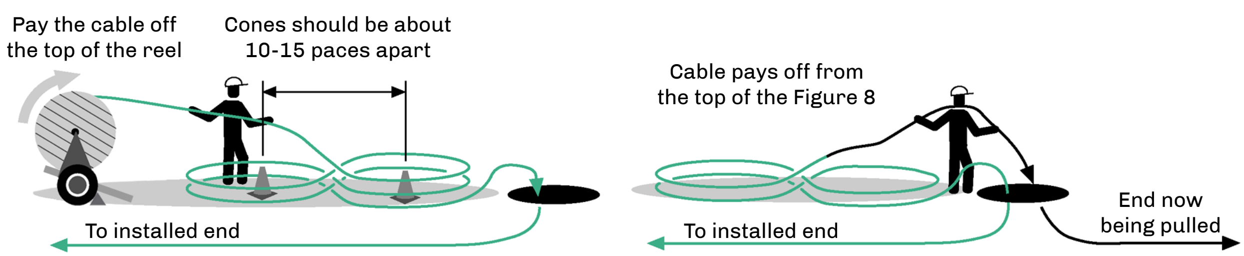
Cable Pulling Methods

Center Pulling — For Long Distances



Courtesy CommScope Properties, LLC

1. Pull longest section (4,000 feet) into assigned duct from MH3 to MH1. For long pulls, use a mid-point (MH3), if needed, to evenly distribute the pulling length and tension.
2. Remove remainder of cable from shipping reel and lay into Figure 8 loops (at MH3). Be sure that loops are laid carefully one upon another and are protected from vehicular and personnel traffic. This cable now can be pulled back into the opposite duct to MH4 and MH5.
3. Feed the cable end into the conduit and continue pulling. Good communication among the installers is necessary to ensure that no damage occurs.
4. For extremely long pulls, remove the cable at a manhole further down the route, and Figure 8 or zigzag it while pulling equipment is moved to the next manhole site.



Courtesy CommScope Properties, LLC

Remember:

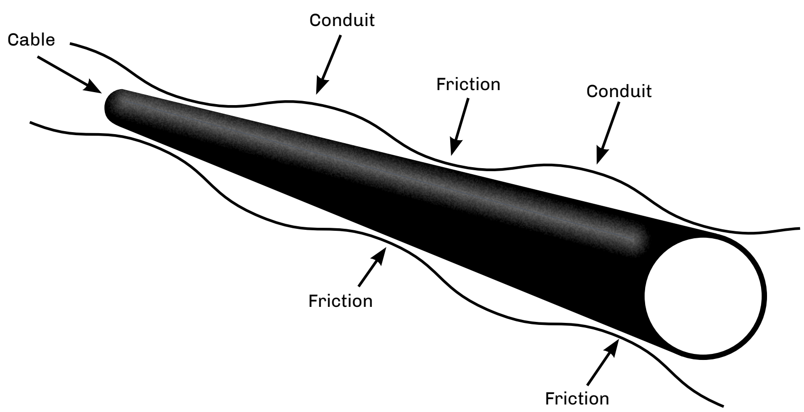
- For long lengths, use center pull methods.
- Long pulls are desirable.
- Minimize pulls through elbows. A 90° elbow is equivalent to 200 meters (656 feet) of straight pulling.
- Do not force cable around sharp corners.
- Do not force or tug the cable during manual installations.
- Do not wrap cable around hands or wrist during handling.
- Seal all ducts with duct plugs.
- Order ducts and innerducts with pulling line pre-installed.
- Innerduct stretches under tension.

Cable Pulling Lubricants

In ducted installations, lubricants are used to reduce the friction between the wall of the innerduct and the cable's jacket. Fiber optic lubricants are designed for maximum tension reduction and reduce friction better than conventional lubricants. For most long or high-friction installations, pulling lubrication will be needed.

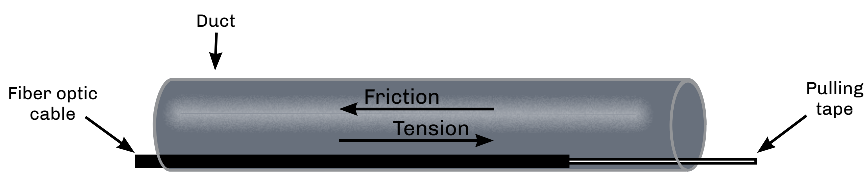
These lubricants are usually water-based materials with soluble high polymers that make them slippery. Some contain silicone oils or microspheres that act like tiny ball bearings to reduce friction. For long pulls, it is important that the lubricant completely coats the cable jacket and stays on the cable throughout the length of the run.

When choosing a lubricant, remember that it must be compatible with the cable jacket, duct materials, and installation method, and must be rated for the ambient temperature during installation. Some cable manufacturers maintain lists of appropriate lubricants for use with their cable's jacket. Lubricant manufacturers provide application equipment ranging from hand pumps, T-style applicators, and various styles of lubrication saddles to make the job clean, easy, and efficient for the installer.



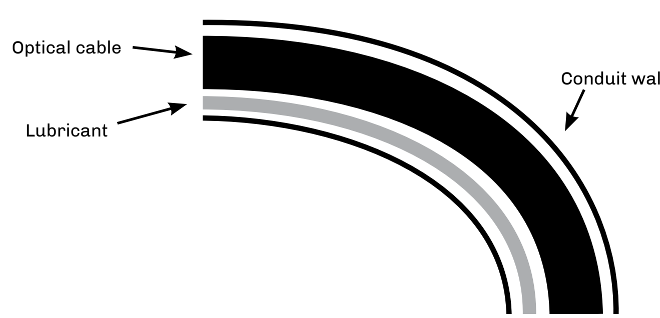
A fiber optic cable can rub on all sides of conduit.

On straight runs, the friction is primarily located at the bottom of the cable.



Courtesy American Polywater

When cables are pulled through turns, the cable can rub the inside angle due to high pulling stresses. Lubricants decrease this friction by having the cable ride on a thin layer of lubricant.



Tension Monitoring

When mechanical pulling equipment is used, the risk of exceeding the manufacturer's maximum rated tension levels is increased. It is recommended that all cables be monitored to prevent exceeding the manufacturer's tension rating in order to minimize potential damage to the fiber optic cable and its internal fibers. Most outdoor cables are rated with a maximum tension level of 600 pounds. Microduct and FTTx drop cables are rated at 300 pounds. All-dielectric self-supporting (ADSS) cables are designed for long spans and can have tension levels of thousands of pounds.

Equipment

- Dynamometer.
- Strain gauge.
- Tensiometer.

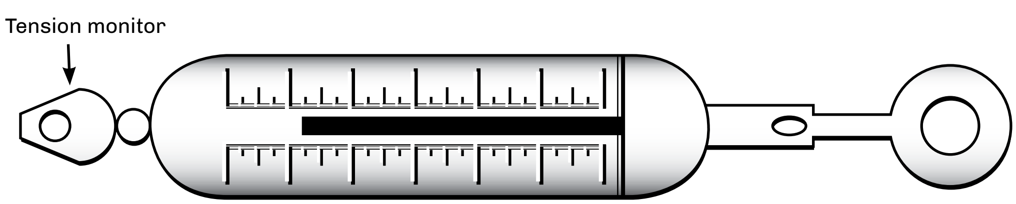
These devices are placed at the pulling end of the installation to allow continual monitoring of the pulling tension by the operator.

During the engineering study, a calculated tension number may be assigned for each section to be installed. The use of a monitoring device can provide on-site comparisons with the projected tension levels.

The dynamometer is the most predominant of the strain measurement devices. This device should have two indicators: A black indicator to measure the tension as it occurs, and a red indicator to maintain the maximum tension obtained during the pull.

The dynamometer should be compatible with the various types of pull ropes, tapes, aramid, etc., that are used for the installations.

Occasional calibration may be required as a dynamometer is a precision instrument.



Dynamometer

Even with proper tension during an installation, it is recommended that the first three meters of cable be discarded due to possible damage.

- Most outdoor cables are rated with a maximum tension of 600 pounds.
- Microduct and FTTx drop cables are rated at 300 pounds.
- Tension devices allow continual monitoring of the pulling tension.
- To prevent damage, do not exceed the manufacturer's tension rating.

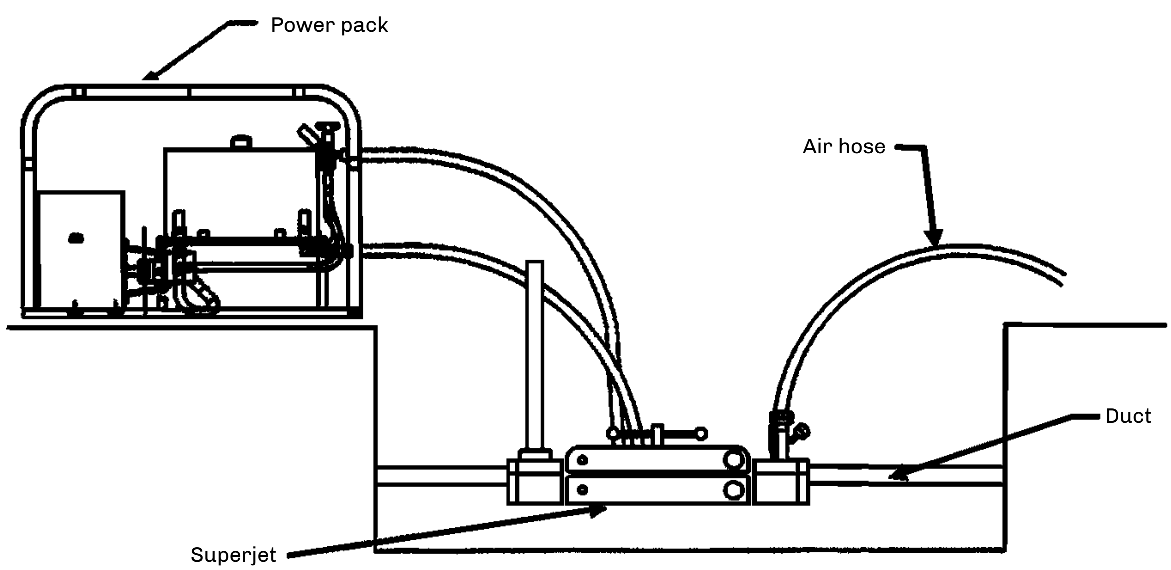
High Air Speed Blown

The high air speed blown (HASB) installation technique was invented in 1986 by the Dutch PTT. This cable installation method differs from others in that it exclusively uses a low-strain pushing force combined with the high speed of compressed air flowing over the cable's outer jacket in a duct or pipe to move the cable *without the use* of an air-capturing device at the cable-end. This dramatically reduces friction between the cable and duct, reducing the installation tensions.

The basis for the invention was the need to install small outside plant fiber optic cables in underground ducts. It has become the method of choice for both urban and long-haul installations when job parameters will allow for its use.

To install an optical cable using HASB technology, a large capacity air compressor is set up at the blowing head location. The fiber optic cable passes through a set of hydraulic powered tracks that pushes the cable into the blowing head and into the duct system. High-pressure air enters the blowing head and is directed coaxially along the cable into the duct, creating a high-velocity air stream that drags the cable through the duct. The drag forces are distributed along the entire length of the cable, eliminating the tensile forces concentrated at one end of the cable during conventional pulls. The distributed force on the cable is high enough to overcome friction and is so small that the cable can easily be stopped by holding it in one hand.

A hydraulic pusher is required to overcome the local resistance of the blowing head and its internal seals and does not push the cable through the duct. It also acts as the controlling device for starting, stopping, and regulating cable speed.



Courtesy Sherman & Reilly, Inc.

- Low-strain pushing force combined with high-speed compressed air.
- Reduces friction between cable and duct.
- Method of choice for urban and long-haul installations.
- Cables are installed virtually stress-free.
- 40% cost savings are common.

Aerial Placement

Proper route planning and engineering.

Equipment requirements.

Installation techniques.

Introduction

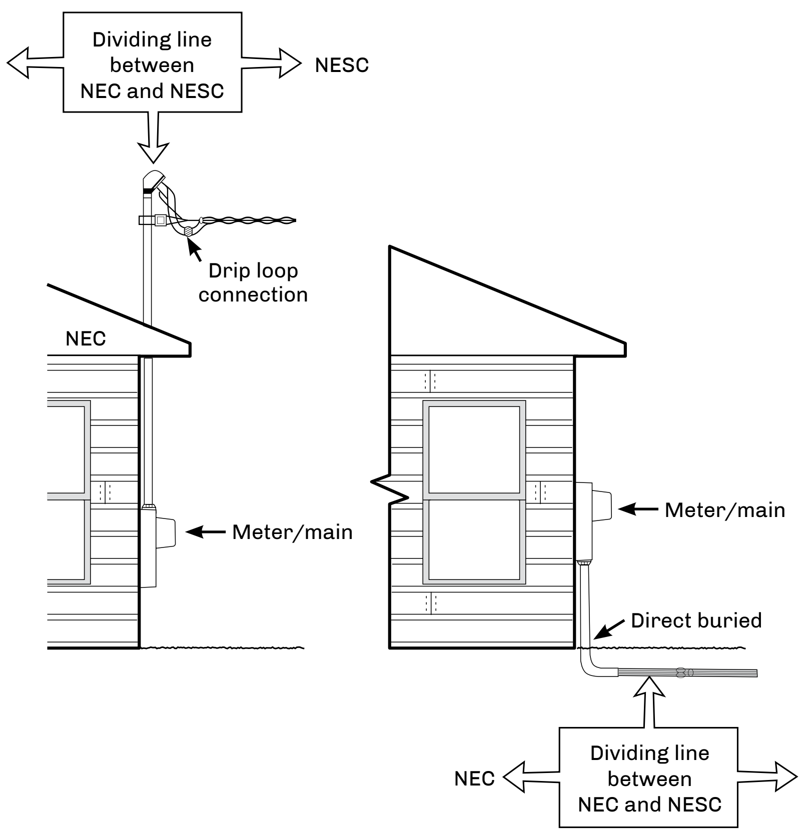
Aerial placement of fiber optic cable is dependent upon the terrain, the application, and the benefits it offers. The immunity of fiber optics to electromagnetic interference (EMI) combined with its lighter weight and smaller size make optical cables an attractive alternative to use in aerial installations. With its lighter weight, optical cable can be used for longer spans and much greater lengths between splices.

Often, it is the most cost effective due to existing rights of way (ROW). For most telephony installations, concerns about ROW and high-voltage power lines do not necessarily apply. For utility applications, more detail is required because of the surrounding effects created by high-voltage power lines.

Installation options include overlashing or self-supporting cable.

Special Note

Check with all construction, utility, and safety codes that may specify methods, practices, and requirements for the design, installation, and safety for aerial applications. The National Electric Safety Code (NESC), issued by ANSI, contains most of the requirements for aerial and underground installations.



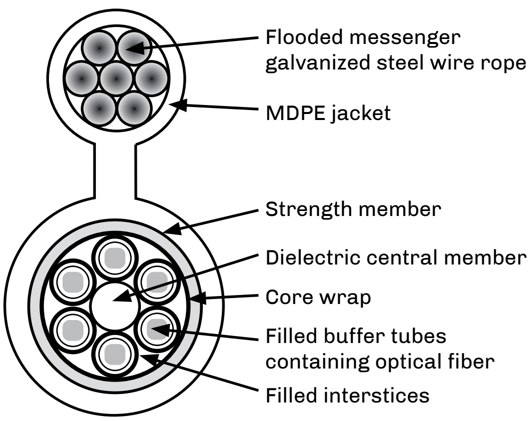
Courtesy NESC

Aerial Cable Types

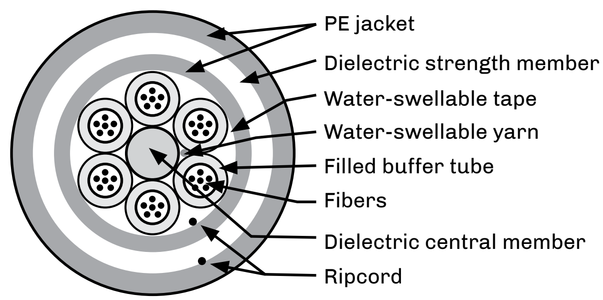
Loose tube	Cable overlashed to messenger
Figure 8	With built-in messenger
ADSS	All-dielectric self-supporting
OPGW	Optical ground wire
Wrapped	Dielectric cable wrapped around existing neutral or phone conductors

Aerial cables must be specifically designed to handle the environment over their life span. Wind and ice loading, pollution, UV radiation, thermal cycling, stress, and aging are a few considerations that must be addressed when selecting aerial cable. Several styles are available, varying based on intended placement, application, and environment.

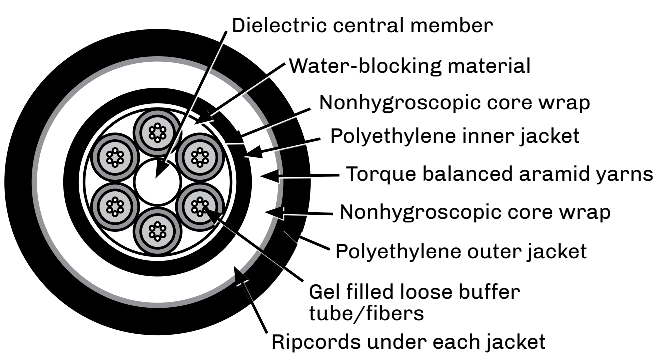
Figure 8



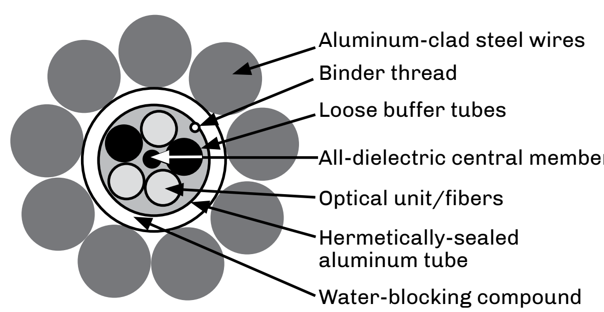
Loose Tube Overlashed to Messenger



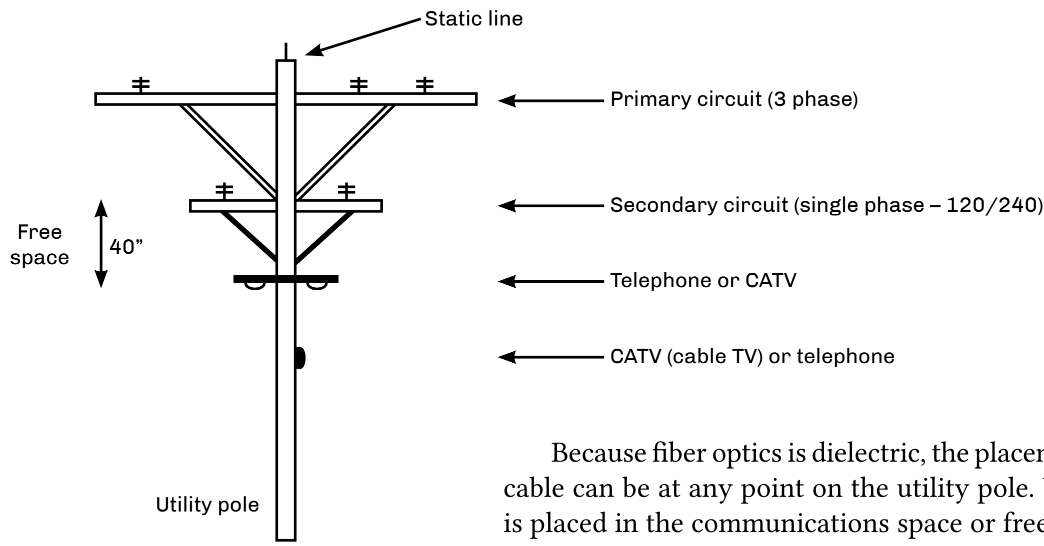
All-dielectric Self-supporting (ADSS)



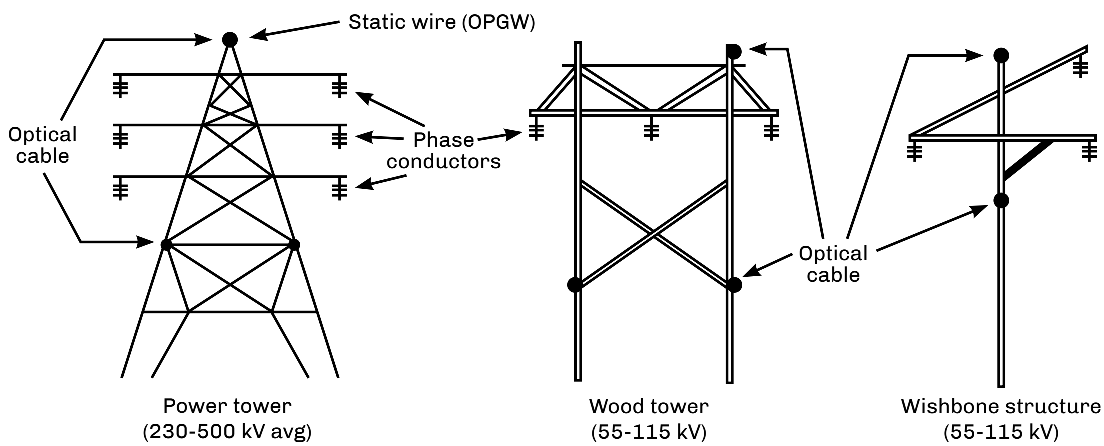
Optical Ground Wire (OPGW)
Utility Static Wire



Typical Pole Placement



Because fiber optics is dielectric, the placement of the optical cable can be at any point on the utility pole. Usually, the cable is placed in the communications space or free space.



Note: Clearance from ground, water, roads, railroads and or other mediums must be considered. Check the ruling regulations for proper heights, clearances and other concerns.

Clearances

Section 23 of the National Electric Safety Code (NESC) describes vertical clearances over the ground, between conductors carried on different supporting structures and required separation distance of the cable from bridges, buildings, and other structures. Local electrical codes and utility representatives may determine the actual amount of clearance between the broadband cable and power cabling.

The basic clearance rules are specified at an air temperature of 60°F (15.5°C). The typical clearance of the lowest cable over streets and roads carrying truck traffic is 18’. In residential areas, the required clearance over driveways is 16’. The typical vertical clearance at a pole between power secondary conductors and the broadband cable is 40”. If such a placement leaves less than 30” clearance in the middle of the span, increase the pole clearance to provide the midspan clearance.

Aerial Installation

Span Length and Sag

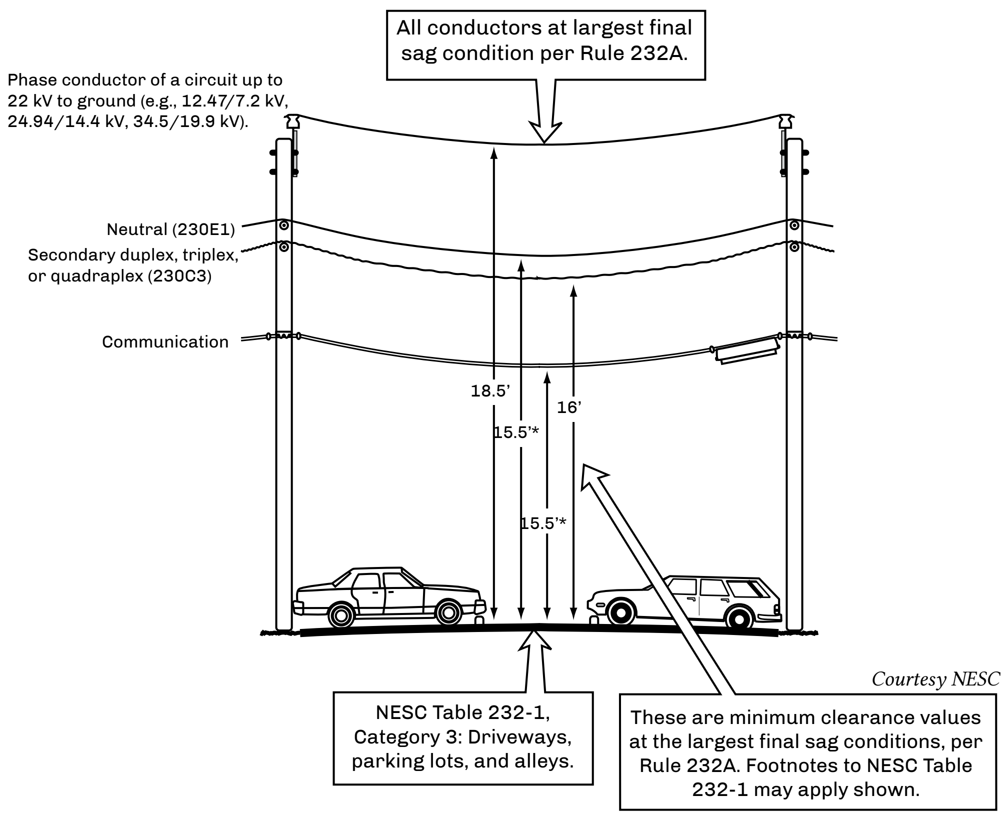
Span Length

The span length of an optical installation depends upon several criteria. These are:

- Maximum allowed cable tension.
- Maximum sag limitations.
- Environmental conditions.
    - Wind and ice loading.
    - Expansion contraction.
- Ground clearance.
- Clearance from other conductors.

Sag Considerations

- The less the sag the greater the tension.
- Optical cable does not expand and contract as greatly as metallic cables.
- Some optical cable is lightweight and may display greater drift in wind conditions.
    - Large OPGW or ADSS cables could rival conductors.



Courtesy NESC

*Note: Regardless of the type of cable used (communication or secondary), the minimum clearance from the ground is always 15.5 feet (5 meters).

- Span length, tension and sag are directly related.
- You cannot change one without affecting the other.
- You must follow the NESC or any state or local requirements.
- Design and build for worst case scenarios.
- Restorations must match sag per the NESC.

Proper Aerial Route Planning and Engineering

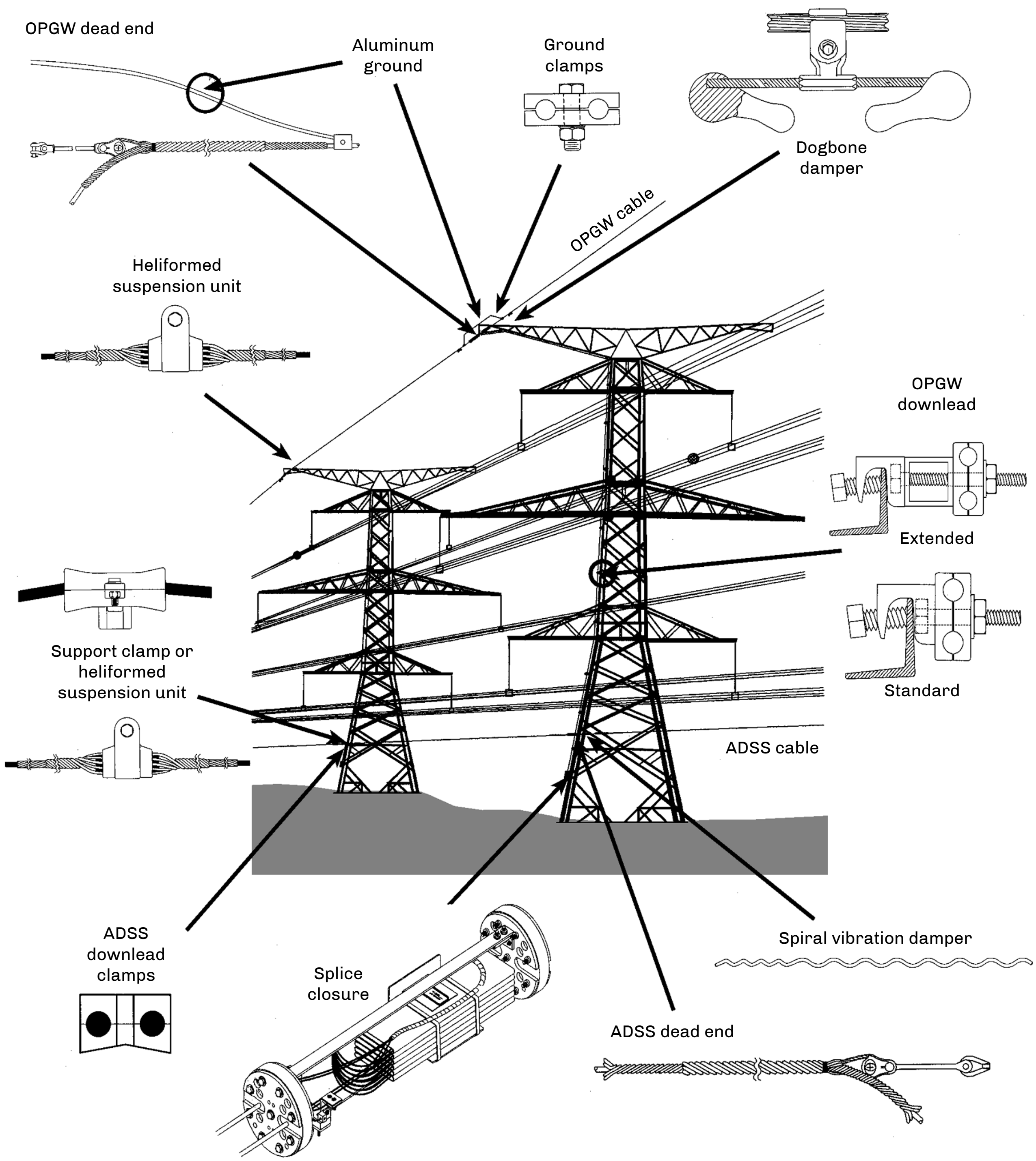
Provided by the outside plant engineer and construction supervisor, the route survey involves the planning and preparation required for a smooth installation.

Route Survey

1. Identify splice locations. Assure that access is available to these points.
2. Determine what environmental problems need to be addressed.
3. Determine what wind and ice loading conditions will be present.
4. Determine aerial installation method and location with regard to aerial poles and existing lines.
5. Determine the maximum tension allowed for the poles or tower. By adjusting the sag, the load or tension on the towers can be increased or decreased.
6. Determine whether any additional clearing will be required.
7. Determine span distances and cable sag requirements. Check for ground clearance. Aesthetics within the cable configurations often require an equal sag for all conductors.
8. Determine cable structure and fiber type. For areas that have hunting or squirrel problems, nondielectric cable may have to be specified.
9. Identify any possible obstructions. Look for areas accessible to vehicles, tools, and test equipment. Clear pole space, easy entrance and exit, and public areas should be considered. Avoid intersections, trees, private property, and potential safety hazards.
10. Determine whether cable will be lashed, strung, or self-supporting.
11. Specify cable reel length and type requirements. Cable length shall coincide with the splice locations. Allow spare cable for splicing points. Excess cable can be coiled and lashed to the strand or placed in a storage cabinet or closure.
12. Determine hardware requirements for placement method chosen. Check horizontal, vertical, or grade changes for appropriate hardware.
13. Specify identification signs and warning markers.
14. Plan for possible future expansions.
15. Develop the route map from all of the above. The map should incorporate all deviations from vertical, horizontal, or grade changes, the locations of poles, splices, and storage areas for the optical cables, as well as grounding points and locations of areas not accessible by vehicles for installations. Cable distance information should also be included with measurements in both feet and meters.
16. Review route survey and planning evaluation of total system design and requirements. This is to ensure no item has been overlooked. Small mistakes can become major ones once the installation begins.

Utility Applications of Fiber Optics

Two types of specialty fiber optic cables have been developed for use in rights-of-ways (ROW) and structures owned by utilities: optical power ground wire (OPGW), for the top of structures, and all-dielectric self-supporting (ADSS), for use at the lower positions on towers and poles.



Aerial Installation Methods

Self-supporting (Integral Messenger)

- Cost effective for new installations.
- Dielectric and nonconductive cable types.
- Long spans.
- ADSS, OPGW, Figure 8.

Lashing

- Cost effective for existing circuits.
- Dielectric and nondielectric lashing wire.
- Loose tube cables.

Wrapping

- Designed for wrapping around existing ground wire or phase conductors (up to 160 kV) of overhead power lines.
- Excellent option for retrofitting for existing installations.
- Easy to install using a radio-controlled spinning machine, which carries the reels of cable (up to 72 fibers). Double wrap technology allows for two cables to be installed.
- Jacket specially designed for utility use on aerial structures.

Aerial Ducts

- Adds additional mechanical protection.
- Used for short distances.
- Must be designed with proper UV-resistant materials.

Note: Aerial installations can be limited by:

- Sag limitations.
- Span length.
- Ground clearances.
- Visual impact.

Comparison of Aerial Installation Techniques

Lashed to Messenger	Self-supporting Cable
Similar to standard industry approved methods for installing normal hard wire system in aerial plant.	Similar to standard industry approved methods for installing normal hard wire system in aerial plant.
1. **Framing of the poles.** a. Prepare the pole by hanging travelers, drilling hardware holes, etc. b. Install pulling lines over obstructions and let the level required for final installation. c. Set tension on all down-guys.	1. **Framing of the poles.** a. Prepare the pole by hanging travelers, drilling holes, hang hardware, etc. b. Install pulling rope.
2. **Install messenger wire.** a. Tension messenger cable for final sag. b. Reinstall pulling lines in travelers for next pull.	
3. **Install fiber optic cable.** a. Pull in optical cable while following manufacturer's maximum tension and minimum bend radius specifications. b. When cable is soft sagged below the messenger level, install dead-ends on both ends leaving drip loops at points of attachment on the poles. c. Install optical cable to messenger using the lashing method. d. Install peanut clamps at points where lashing must be terminated. e. Remove travelers as lashing process is performed.	3. **Install fiber optic cable.** a. Pull in the optical cable. b. Dead-end one end (slack side) of the cable, tension to proper sag, recognizing that Kevlar™ has a very minimal coefficient of change in sag tensions. c. Allow drip loops in fiber at attachment points. d. Remove travelers and attach cable to intermediate poles (clip-in).
4. **Costs associated with installation.** a. Labor dependent on area rates and required crew size. b. Messenger and typical hardware currently $1,200 per mile.	4. **Costs associated with installation.** a. Labor dependent on area rates and required crew size. b. Hardware costs @ $300 per mile, or considerably less than where separate messengers are required.

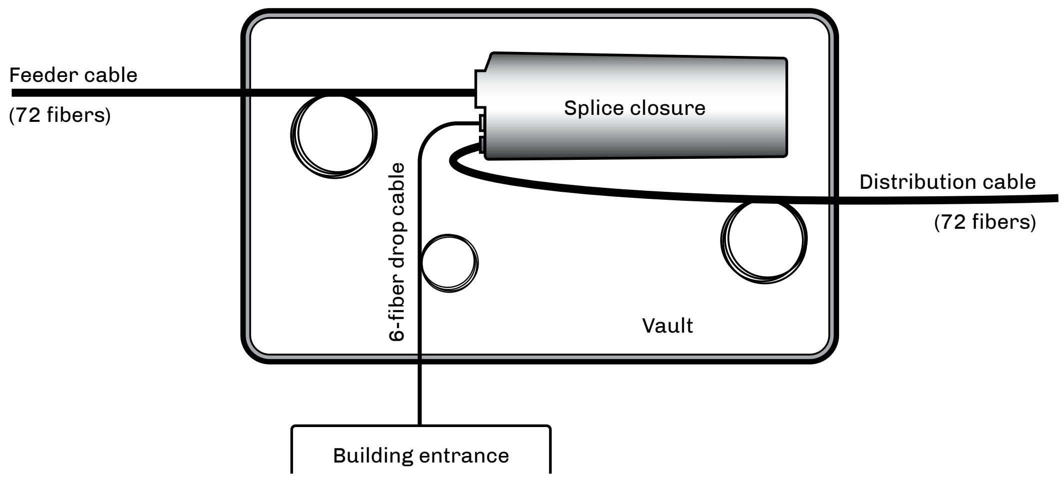
Note: Generally labor rates for the installation of self-supporting cable will be 50% that of the messenger and lashing technique due to the fewer stages. Offsetting this savings is the higher cost (33%) of the self-supporting cable.

Mid-span (Express) Entries

The need to enter a feeder or distribution cable at a mid-section creates a mechanical process that must be considered when designing and building fiber-based networks. Used extensively in metropolitan area networks, and ITS and FTTx installations, the use of the mid-entry site provides a physical add/drop location with great reliability while reducing costs.

Mid-span Entries in the Physical Plant

In many network designs, there are advantages to performing mid-entries to a cable to provide a cost-effective installation and future access. What would be required to perform this type of installation? What products and techniques would need to be specified?



Fiber and Buffer Color Codes (TIA-598 and IEC 60304)

		Tube Color											
		Blue	**Orange**	**Green**	**Brown**	**Slate**	**White**	**Red**	**Black**	**Yellow**	**Violet**	**Rose**	**Aqua**
Fiber Color	**Blue**	1	13	25	37	49	61	73	85	97	109	121	133
	Orange	2	14	26	38	50	62	74	86	98	110	122	134
	Green	3	15	27	39	51	63	75	87	99	111	123	135
	Brown	4	16	28	40	52	64	76	88	100	112	124	136
	Slate	5	17	29	41	53	65	77	89	101	113	125	137
	White	6	18	30	42	54	66	78	90	102	114	126	138
	Red	7	19	31	43	55	67	79	91	103	115	127	139
	Black	8	20	32	44	56	68	80	92	104	116	128	140
	Yellow	9	21	33	45	57	69	81	93	105	117	129	141
	Violet	10	22	34	46	58	70	82	94	106	118	130	142
	Rose	11	23	35	47	59	71	83	95	107	119	131	143
	Aqua	12	24	36	48	60	72	84	96	108	120	132	144

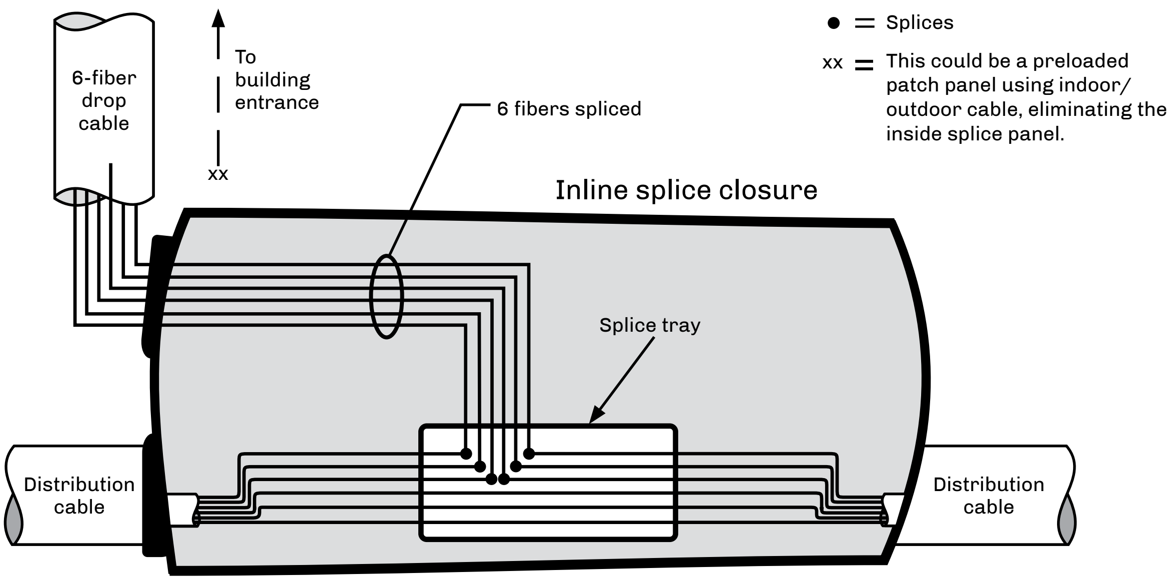
Mid-span (Express) Entries

(Continued)

Fiber Management in Mid-span Entries

A mid-span entry, also known as an express entry, is intended to minimize the amount of splices at the drop point. Using a cable with 72 fibers (six tubes of 12 fibers each), the cost of splicing all 72 fibers at each drop site would be cost prohibitive when only a few fibers are required. For this reason, only one tube needs to be entered and only the required fibers dropped to the desired location.

The technique of dropping only a few fibers from a cable structure allows the designer flexibility to minimize splices, minimize failures and reduce costs. In a ring architecture with self-healing capability, only four splices would be required instead of 72.



Requirement: Splice red tube/fibers (blue, orange, and green) to drop cable (outbound fibers blue, orange, and green) and splice (inbound fibers brown, slate, and white) from the drop cable to the red tube/ fibers (blue, orange, and green) in the ring cable. Note that the slate and white fibers in the drop cables are dark (spare) for future use.

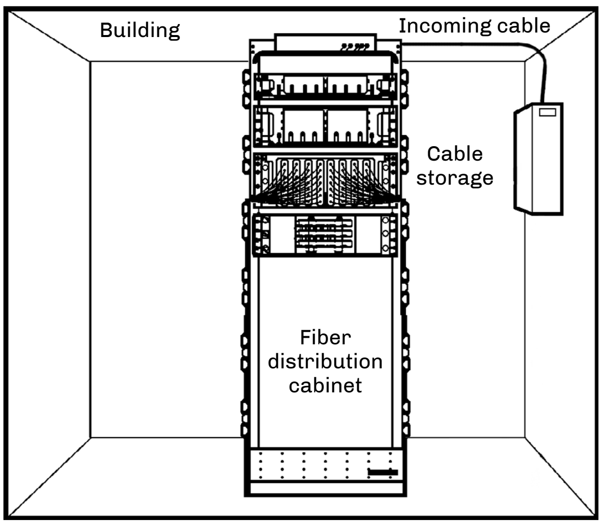
Proper and accurate fiber management is critical to network success. In this case, three fibers are accessed for a total of six splices of the 72 fi bers in the cable. Five of the tubes are still intact with litt le chance of damage if stored in the closure tray properly. In the opened red tube, only three fi bers are cut and the balance are stored in the splice tray.

Note: Cable slack (coils) should be documented in "as-built" drawings and documents.

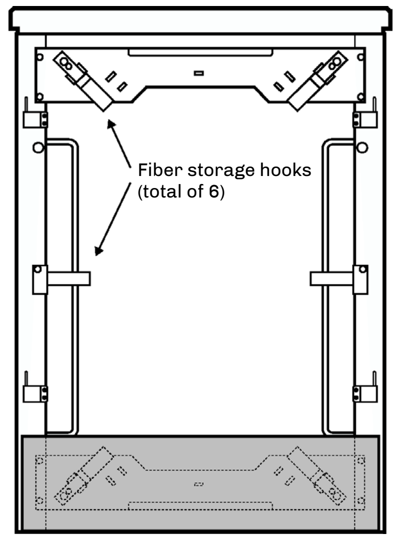
Atte ntion should be paid to the splice closure to assure that a storage tray or basket is used for storing the excess buffer tubes.

Slack Storage Methods

Designed for holding spare or excess cable, storage products allow for flexibility whether used inside building entrance sites or in OSP cable routes. Depending on the application, cable storage products can be aerial, below ground, or above ground. An average amount of slack to be stored is 50 feet, but this can vary depending on the application and space. In the advent of equipment relocation, spare cable can be pulled or stored in the cabinets or vaults. In restorations, retrievable slack can be pulled from storage panels and vaults. This provides time, labor and cost savings.



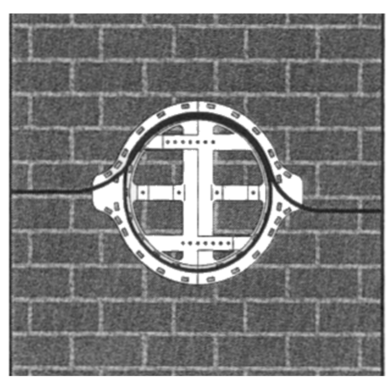
Indoor cable storage cabinet



Above-ground pedestal

Courtesy Moore Diversified Products

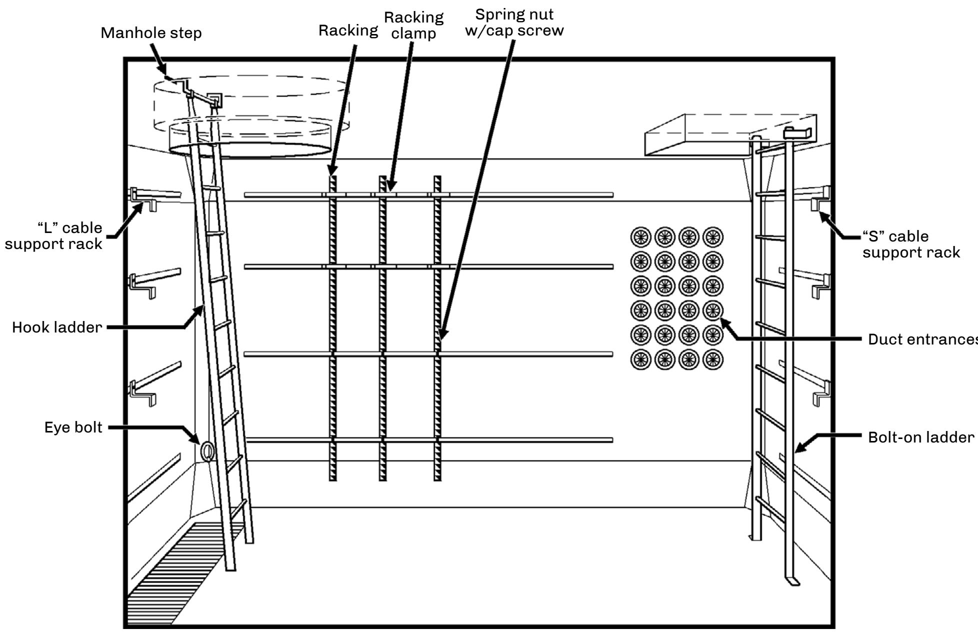
Cable storage allows users to address future adds, moves and changes by allocating spare cable. Common examples of cable storage include vaults, hand holes, below ground load-bearing pedestals, aerial snowshoes, and cable slack rings and cabinets for premises and entrance facilities. The amount of cable stored can depend on the application and the space available.



Wall mount options for inside buildings

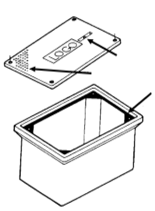
Underground Cable Storage

The installer must maintain the minimum bend radius to ensure optimum integrity and performance of the optical cable. If the cable is conductive, the storage location may be used for bonding and grounding, as defined in applicable codes and standards. Cable labels should be used for quick identification. When storing slack cable the amount of slack should be noted on "as-built" documentation and sequential markings identified for both inbound and outbound cables.



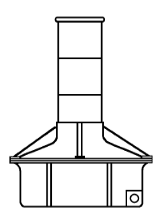
Courtesy Utility Vault Co.

Mid-entry requirements require a vault large enough to store and rack excess cable, the splice closure and handle the minimum bend radius of the cable.



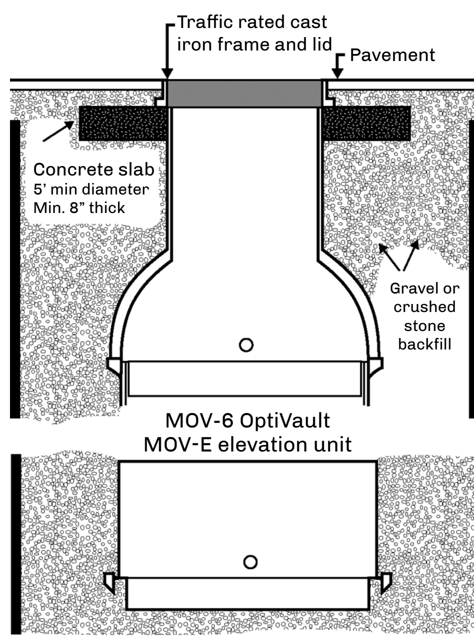
Load bearing handhole

Barrel vault for cable storage



Optiped for cable or closure storage

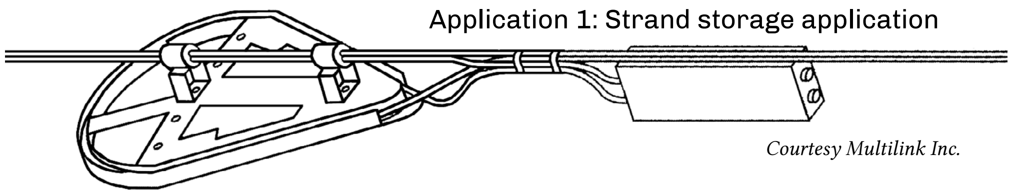
ANSI Z117.1-2009 "Safety Requirements for Confined Spaces"
This establishes the minimum safety requirements for confined space operations, including safeguarding, permits, protective equipment, and emergency response plans.



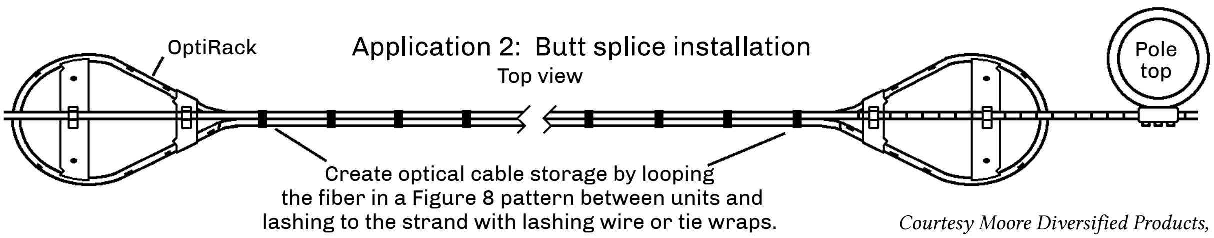
Underground pedestal

Aerial Cable Storage Products

Snowshoes are a simple, low-cost, and aesthetic method for accessing and organizing retrievable cable slack. One snowshoe allows a 180-degree transition when using butt style splice closures. Two snowshoes allow for storing slack as needed. When located near poles, they also provide enough cable slack to allow splice closures, multiport service terminals, and CATV nodes to be lowered to splicing vehicles. They are available in standard diameters of 16” and 24”, as well as a 7” mini version for FTTx drop cables to maintain the cable’s minimum bend radius. Pole and strand mount snowshoes are available in a split version for greater slack cable storage.

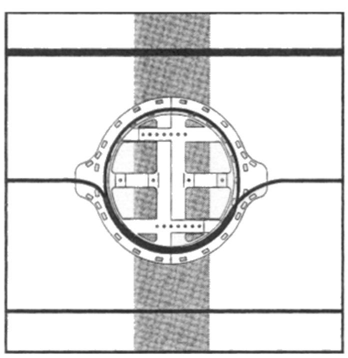


Courtesy Multilink Inc.

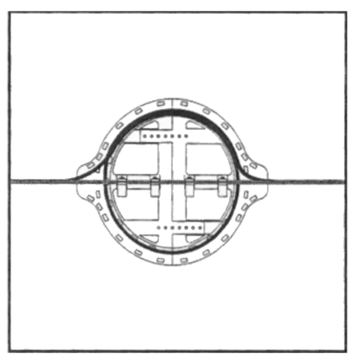


Courtesy Moore Diversified Products, Inc.

Snowshoes for aerial applications



Pole mount



Strand mount

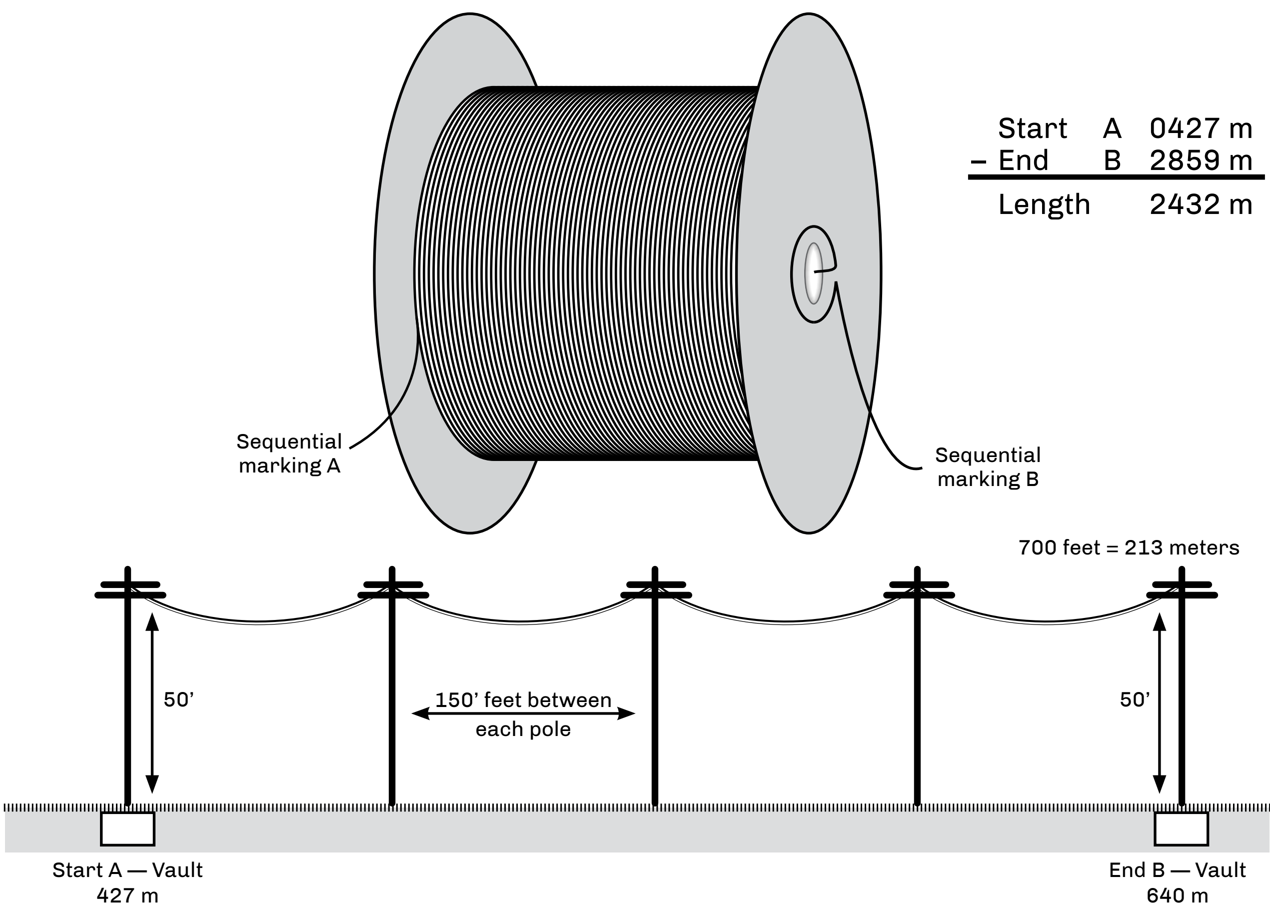
FTTx drop cable slack ring

Sequential Markings

The majority of cables have sequential markings in either footage or meters, which assist in the installation and maintenance of the cable. At slack and splice locations the sequential markings should be documented. This allows for “as-built” documentation to assist in actual cable lengths at fixed locations. At storage points both the incoming and outgoing markings always should be documented and at splice locations the inbound and outbound markings should be noted along with the markings at the inbound and outbound entrances to the storage location.

Complete and accurate system documentation including detailed drawings and troubleshooting procedures are absolutely essential to successful maintenance. Repair crews require route maps detailing actual footage markings of fiber cables to be able to quickly locate trouble spots. Using an OTDR to derive distance to a fiber break is pointless if the user cannot reconcile actual cable distance with geographical distance and locations. Fiber slack within cables as well as cable slack stored in vaults for restoration must also be accounted for in system documentation.

To help manage the copious amounts of documentation required by even the simplest of fiber networks, specialized software packages have been developed to track of detailed maps, routing, splicing diagrams, reports and other maintenance information, including sequential markings. It can even interface with the network itself, monitoring system performance and locating faults. Even the documentation required for multiple fiber routes from FTTH optical splitters and wavelength management in WDM systems can be performed to assist designers, as well as maintenance and restoration staff.



Fiber Installation Inspection Report

The use of an installation inspection report as part of the acceptance test process allows key points in any process (manufacturing, installation etc.) to be identified. By identifying the requirements the installer knows what to do, what is expected and the levels of acceptance.

The following sheets are examples of an installation inspection report for installers of a project. Think about what you would need if you were a manufacturer of components or systems? The benefit is that by identifying the expectations the level of the workmanship and quality tend to increase.

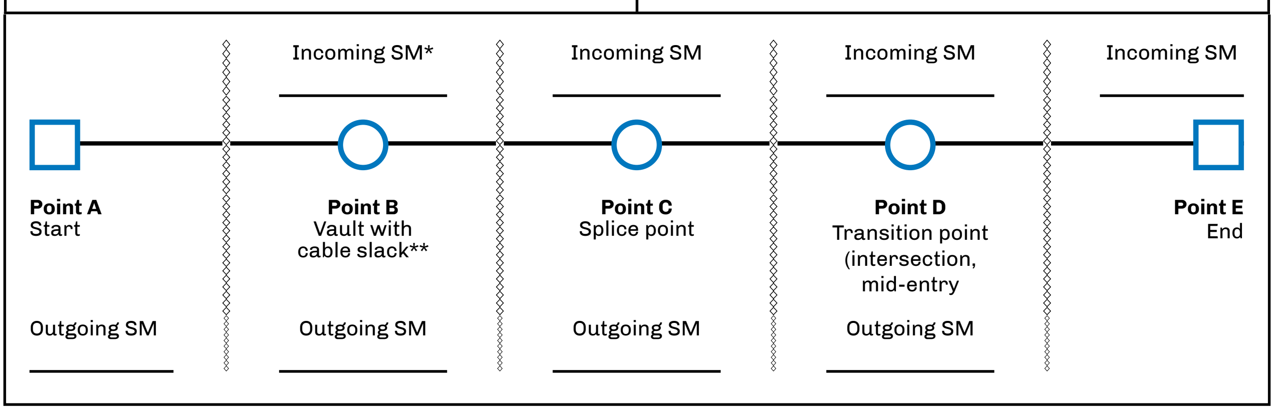
Key Points

- **The header**: Addresses who, when, where, what of any task.
- **Sections**: Break down the tasks by sequential topics.
- **Sub-topics**: Identify specific topics.
- **Grading**: A grading is recorded for each task.
- **Comments**: A area for comments to address specific or generic issues.
- **Sign-off**: Signed and dated by a supervisory person or inspector.

System name	Project #
Span description	Inspection date

Sequential markings (meter/feet)

Start A (outgoing)	Point B (incoming)
Point B (outgoing)	Point C (incoming)
Point C (outgoing)	Point D (incoming)
Point D (outgoing)	End



* In this case, SM stands for "sequential marking". Note that sequential markings usually change at transition (splice) locations. Types of changes can include the direction of the markings, the unit of measurement (feet, meters), or numeric.

** The difference between incoming and outgoing numbers identifies and verifies the amount of slack.

Chapter 9 Review

1. What do the sequential markings help the cable installer to determine?

2. What should a cable installer be aware of when installing fiber optic cables into a conduit?

3. What is the maximum fill percentage ratio by cross-sectional area for a conduit with one cable?

4. What is recommended to have for future changes and restorations?

5. What are three primary methods for underground installation of fiber optic cable?

6. What does the acronym HASB signify?

7. What is the main benefit of an HASB installation?

8. What does the acronym NESC represent?

9. What information is contained in the NESC?

10. What does the acronym ADSS stand for?

Chapter 9 Review

11. What are two very important considerations when installing an aerial fiber optic cable?

12. What is a mid-span entry?

13. True or false: Maxcell bags were designed not only to separate and maximize duct space but also to decrease cable friction.

14. What is the most common method of installing aerial cables for telephone and CATV organizations?

Chapter 10

Test Equipment

By the end of this chapter, you will be able to:

- Explain what an OTDR does and how it operates
- Summarize the testing applications of an OTDR
- Summarize the testing applications of an optical power meter
- Compare and contrast fiber identifiers and visual fault locators
- List the wavelengths used to measure multimode fiber spans
- List the wavelengths used to measure single-mode fiber spans

Tests and Equipment

Physical Plant

Test	Equipment
Cable acceptance test from manufacturer	OTDR (length and dB/km)
Cable span continuity test after installation (prior to splicing)	OTDR
Splice attenuation	OTDR
Fault location	OTDR/fiber break locator
Cable span signatures	OTDR
Optical return loss (span)	OTDR, terminator and deadzone box or ORL reflectometer
Reflection testing (component)	OTDR deadzone box and terminator
Receivable power of optical cable	Power meter
Transmitter output power	Power meter
Communications	Fiber optic talk set
Faulty pigtail/splice	Visible laser
Identifying live fibers	Fiber identifier

Network, Fiber and Components

Test	Equipment
Polarization mode dispersion (PMD)	PMD test set
Chromatic dispersion	CD test set
System test (optical power margin)	Variable attenuator and bit error rate tester
Ethernet/IP testing	Network analyzer
Laser/LED/detector/WDM analysis wavelength measurements	Optical spectrum analyzer and multiwavelength meter Optical component analyzer
Source/detector testing	O/E and E/O converter and optical spectrum analyzer

Optical Loss Test Sets

Optical loss testing is required to provide accurate end-to-end loss measurements of a fiber optic span. The test equipment involved consists of an optical light source (OLS) and an optical power meter (OPM), which can function either as separate units that measure attenuation in one direction, or as one integrated unit called an optical loss test set (OLTS). While OLTS require two units, they provide bidirectional testing.

If the testing units are individual OLS and OPM devices, there must be a technician at one end of the span with the OLS and another at the opposite end with the OPM. These are linked via jumpers at patch panels, interconnecting the span to be tested. After all tests are performed, the two technicians must swap locations to measure the attenuation in the opposite direction. The longer the span the more complex this becomes, especially for service providers in wide and metropolitan area networks. In such cases, it is recommended to use an OLTS since it can operate bidirectionally and at the dual wavelengths required. This is normally 850 nm and 1300 nm for multimode applications, and 1310 and 1550 nm for single-mode applications.

Applications

- Continuity check.
- Transmit power level.
- Receive power level.
- End-to-end performance test between patch panels.

Power Meter

Features and options to consider:

- Warranty and calibration interval
- Power measurements (dBm).
- Referencing (zeroing) capability.
- Resolution specification (min. 0.01 dB).
- Selectable wavelengths.
- Standard batteries.
- Size and weight.
- Operating temperature range.
- Dynamic range.

Light Source

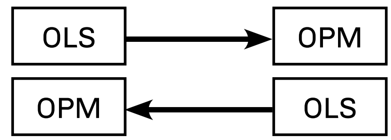
Select one with the following features:

- Warranty and calibration interval
- **Stabilized**, for accurate measurements.
- Laser or LED wavelengths.
  - Multimode: 850 nm and 1300 nm.
  - Single-mode: 1310 nm and 1550 nm.
- Connector type.
- Output power.
- Standard batteries.
- Size and weight.
- Tone generation for use with fiber identifiers.

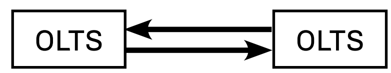
Optical Loss Test Equipment

1. **One light source (OLS) and one optical power meter (OPM).**
   - Must use external communication systems (fiber talk set, radios, phones at end locations).
   - Tests in only one direction. This requires the two technicians to reverse and retest in the opposite direction.
   - Technician with power meter documents test results.

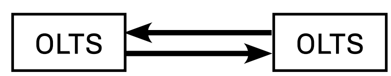
2. **Two sets of light sources and power meters.**
   - Requires external communication systems.
   - Tests in both directions using different fibers. After testing all the fibers, the technicians must roll the sets to allow testing in the opposite direction.
   - Both technicians document test results.



3. **Optical loss test sets** (consisting of units with built-in light sources and power meters).
   - May require external communication systems.
   - Optional talk set option.
   - Both technicians document test results from built-in power meters.



4. **Optical loss test sets with certification.**
   - Optional built-in talk set.
   - Units handshake to calibrate for testing.
   - Units perform optical loss test and reflection tests.
   - Bidirectional test performed.
   - Dual-wavelength tests performed.
   - Results compared against standard for pass/fail indication.
   - 2-kHz detection option on single-mode units.
   - Automated menu testing options.
   - FTTx test sets must operate at 1310, 1490, 1550 nm and incorporate in-line handshaking between the OLT and ONT.



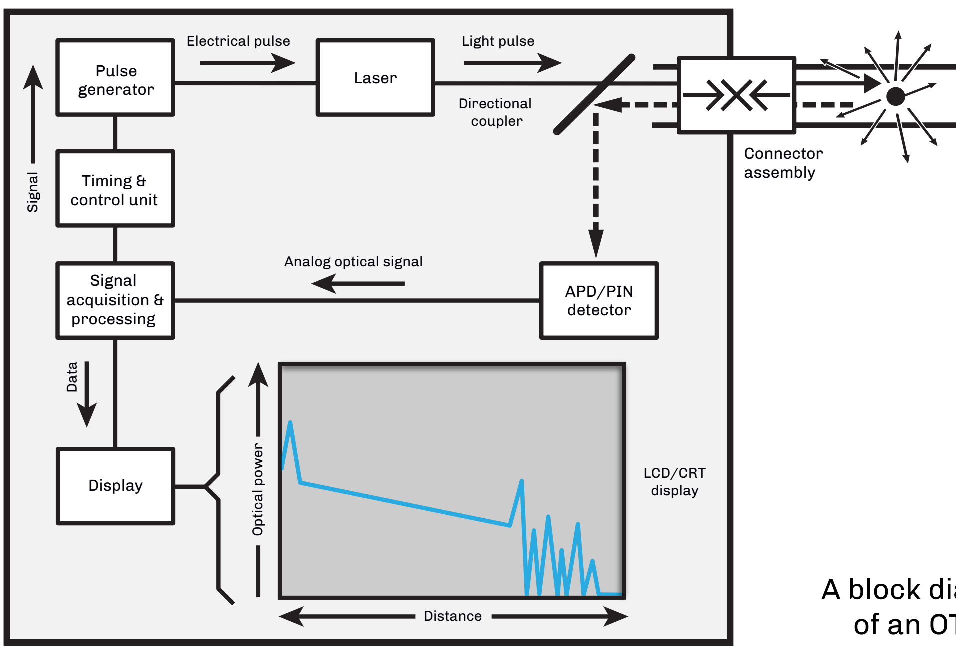
The OTDR

The optical time-domain reflectometer (OTDR) is a one-person bidirectional instrument that operates on the optical principle of Rayleigh backscatter and Fresnel reflections. It is used to measure the length and attenuation of optical fiber spans and to determine the distance to events and faults.

OTDR Applications

- Measuring fiber length.
- Measuring distance to faults, splices, connectors, and stresses placed on the fiber.
- Measuring reflectance of components.
- Measuring optical return loss of spans.
- Measuring loss as dB and dB/km.
- Measuring splice loss.
- Cable monitoring.
- Documentation.

How the OTDR Works



A block diagram of an OTDR.

An OTDR both transmits and receives optical energy, which is required in order for it to be able to measure the amount of backscattered light from the optical fiber. The timing and control unit sends a signal to the pulse generator, which in turn sends an electrical pulse to the laser, causing it to emit a pulse of light. This light pulse is directed through an optical coupler and sent to the optical fiber under test. Light pulses from optical fiber connections, impurities, damage, or from the end of the optical fiber itself are reflected through the optical coupler and directed to the detector. The optical signal is then amplified and converted to an electrical analog signal by the signal acquisition and processing unit. An analog-to-digital converter in the signal acquisition and processing unit changes the analog signal to a digital signal. This digital signal is stored in the data acquisition memory. This scanning process is repeated several times. The data is processed and transmitted to the OTDR's LCD or CRT display.

The OTDR Family of Products

Hand-held OTDR

Hand-held OTDRs are small, lightweight, and user-friendly. Most have touchscreens and simple functions, and can be used as a display for inspection probes. They allow problems to be easily identified with trace overlays. USB storage makes recording traces easy and the unit can be powered with both AC and DC.

- Small.
- Lightweight.
- User-friendly.
- USB storage.
- AC/DC power.

Fiber Break Locator

The least expensive and easiest to use, most fault locators have simplified the specialized features of the OTDR. A simple, lightweight, easy-to-use instrument for fault locating with an LCD display, disk storage and AC or DC operation, it is a nice fit for those who only need to locate network faults.

Modular OTDR

In modular instruments, the OTDR function is just one of the many optional function modules available. Other modules include optical spectrum analyzer (OSA), chromatic dispersion (CD), polarization mode dispersion (PMD), optical switch, and an optical microscope for ferrule/fiber inspection. Many include a digital microscope with both male and female capabilities. The instruments can also store the pictures for documentation purposes.

A modular OTDR is less prone to obsolescence and is easier to add features for future applications. As new tests and methods emerge, new modules become available to allow it to keep pace with changing technology.

- Optional function modules.
    - OTDR.
    - Optical spectrum analyzer.
    - PMD and CD.
- Optical switch.

Key Considerations for All OTDRs

1. What is the true dynamic range? This will be called out as backscatter (in dB) at a specified wavelength. The specifications for Fresnel reflection applies to spikes in the signature, which won't help you if the cable is cut and the trace is below the noise floor of the instrument.

2. What is the true deadzone? How close to the instrument (or between events) can I actually measure a nonreflective fault? This would be measured when operating the OTDR at its shortest pulse width.

3. What are the printing and storage options? Many instruments offer USB ports for flash drives, internal hard drive, Bluetooth, and cloud storage. Remember:
   a. Storage requires software that is compatible with your application. Not all OTDR manufacturers have software that meets Telcordia GR-196-CORE standards.

4. Does the instrument default during start-up or can you program the instrument?

5. Does the instrument have an easy recall feature? Overlay? Update?

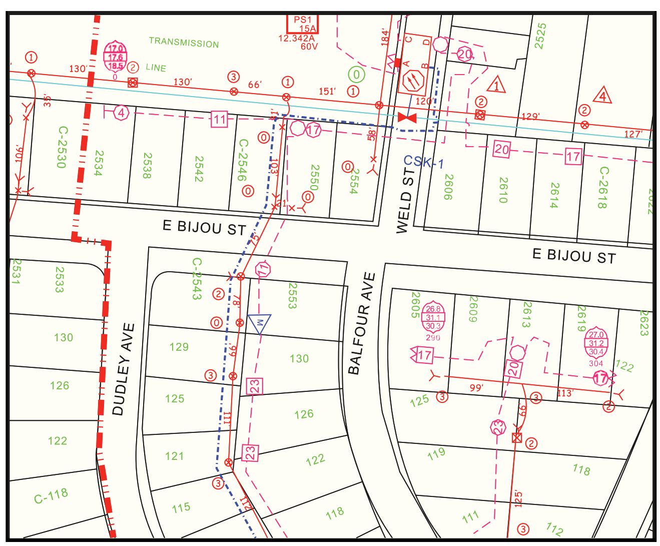
6. Can you switch functions quickly without having to go deep within the menu functions? For example, operating in real time for acceptance testing and then switch to averaging for dB/km and length measurements?

7. Does the OTDR have the capability to test both optical return loss (ORL) and reflectance?

8. Consider factory support, warranty and training options.

Buy the best instrument for your applications. Basic features are what you need. Forget all the enhanced features if they are not needed. Concentrate on evaluating the equipment for the functions you will use:

- Acceptance testing.
- Span acceptance, splice loss.
- Restoration.
- Short distance, high resolution.
- Long distance, high resolution (e.g., FTTx).
- Long range.



How do we locate the cable break geographically?
Documentation!

Fiber Identifiers

Optical fiber identifiers (OFIs) are used extensively when mid-entries or access to single-mode optical fibers is required. They detect live traffic signals or a modulated test signal on an individual optical fiber. An OFI does this with minimal attenuation by putting a controlled macrobend on the optical fiber that allows the escape and detection of light energy. The user can expect approximately a 0.2 dB loss at 1310 nm and a 2.0 dB loss at 1550 nm when using an OFI. The OFI can also detect from which direction the traffic is being received due to two detectors placed to detect the transmission of light and determine its direction of travel. OFIs are designed for different fiber coatings such as 250-µm and 900-µm coatings, jacket sizes up to 3 mm (used in jumpers and pigtails), and have optional adapters for ribbon fibers.

1. **Applications.**
   a. Determines active or inactive fibers.
   b. Allows troubleshooting of multiple fiber strands without disrupting the network.
   c. Verification of color code charts.
   d. Identifies direction of transmission path.
2. **Features.**
   a. Optional remote probe.
   b. Optional clamp assembly.
   c. Visible activity indicator.
   d. 2-kHz modulation used for identification.
3. **Specifications.**
   a. Spectral range or detectable optical wavelengths is usually 800-1600 nm.
   b. With CW operation, range is typically 0-35 dBm and 0-45 dBm using the 2-kHz modulation.
   c. Detection range of +20 to −20 dBm.

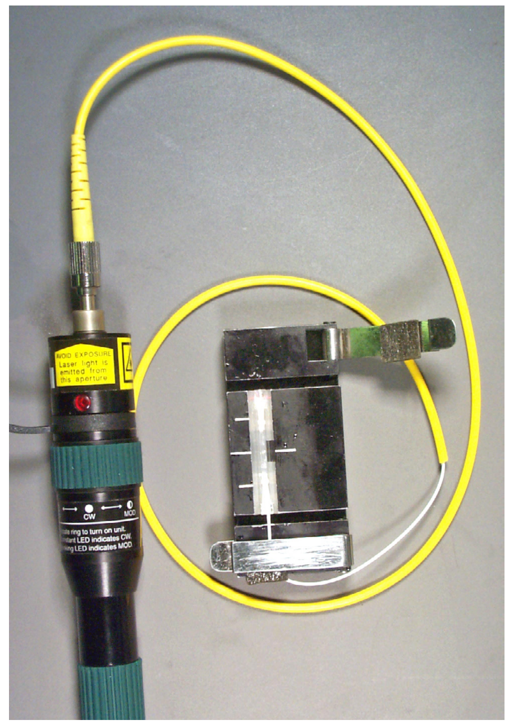
Note: The accuracy of fiber identifiers with G.657 bend-insensitive fiber depends on the dynamic range of the detector, the distance, and G.657 fiber type and classification.

Visual Tracers

A low-cost, simple-to-use continuity tester, visual tracers give users of optical-fiber systems the capability to trace fiber routes for end-to-end continuity and, with the more powerful laser versions, to locate fiber faults in 3-mm cordage and 250-µm and 900-µm coated fibers.

White light sources can be used for end-to-end continuity testing up to 2 km, but don't provide enough power to locate breaks and stresses. In these cases, a visible red laser is used.

- For spans up to 2 km (Class II) and up to 4 km (Class IIIA).
- Locates:
  - Breaks within an OTDR's deadzone.
  - Bad splices.
  - Microbends and macrobends.
  - Potential fiber problems (imperfections).
- Can be used as a fiber identifier.
- Quick troubleshooting of connectors and short drop cables.
- Can operate on multimode or single-mode fibers.
- Operates independent of the transmission wavelength.
- Terminates with a jumper or pigtail.
- Class II (≤1 mW) or Class IIIA (≤5 mW) visible red laser operating at 630 to 670 nm.



Fault locators are very good instruments for locating faults and other anomalies where the pulse width of the laser used in OTDRs will not allow measurements to be made. However, some OTDRs use visual laser options.

Even though manufacturers have built-in key lock systems, beam guards, and other methods of preventing retina damage, the possibility exists of accidentally looking into the end of jumper and pigtails. It is best to wear semi-filtered helium neon goggles. The user needs to see the beam but the goggles will give protection from exposure.

Visual Inspection

Although every fiber connector should be cleaned prior to use or testing, in the past, connector inspection was primarily performed to prevent surface debris from damaging the optical surfaces and to identify connector surface conditions during polishing processes.

The most critical part of the fiber is the core and the area that immediately surrounds it. Damage in the outer part of the cladding will normally not affect the transmission signal. Always clean a connector prior to inspection in order to differentiate contaminants versus damage.

It has been found that greater detail is required in identifying contaminants with examples that are more realistic to today's fiber optic manufacturers and users.

The IEC 61300-3-35 document sets requirements for allowable surface defects that may affect optical performance including:

Scratches – Permanent linear surface features derived from polishing or handling.

Pits – Permanent nonlinear features caused during polishing or handling.

Cracks – Permanent fracture lines that may extend to the surface of the fiber.

Surface debris – Nonpermanent features that can be removed by cleaning.

Resolution – 1 μm (micron).

Inspection Scopes

Microscopes are used to visual checking the surface quality of fiber optic connectors. These 200X microscopes generally have filters to protect against laser beams. However, caution should be taken. Live optical fibers should never be viewed and light sources should be turned off. New digital scopes are safer and images can be stored for future reference or comparison.

- Used to check connector and fiber endfaces.
- Connector and bare fiber adapters.
- 200x-400x magnification.
  - 200x recommended.
- Built-in safety filter is required
- Always clean endfaces prior to inspection.

* TIA-455-240 or 57B and IEC 61300 standards.

Visual Inspection

(Continued)

Digital Video Inspection Scopes

Digital video-based inspection scopes display a visual image of the fiber and their digital images can be stored for later comparison as a maintenance tool. Digital video scopes can examine the end faces of the ferrules used in the plugs, as well as to inspect the bulkhead connectors in patch panels or transmitter and receiver ports, and are safer to use than microscopes.

- LCD screen provides retina safe viewing.
- Stores and recalls digital images.
- Connector and bulkhead adapter tips available.
- Automatic pass/fail analysis.
- Auto focus.
- Can connect to test equipment or have their own screens

CCD Array Camera With Monitor

Used in manufacturing plants or where incoming cable assembly inspections are performed, the bench top inspection station consists of an optical microscope and an CCD array camera that project an image of the ferrule/termini's fibers end-face onto a video monitor. This technique allows for safe visual inspection of the surface quality of devices. Since the viewer sees the picture rather than the direct magnified image, this method works well in manufacturing locations where is it easier to view without looking into a microscope.

- The total (electronic) magnification is the total of the optical and video magnification.
- The optical magnification is defined as the power of the objective lens multiplied by any video lens incorporated between the objective and CCD camera.
- Video magnification is defined as the ratio of the diagonal of the monitor divided by the camera chip size.

Optical Talk Sets

The optical talk set is used for communications during installation, testing, and restoration programs. It uses the optical fiber as the communications media.

1. **Applications.**
   - Optical loss test situations.
     - Used between the light source (send) and the power meter (receive).
   - Used for splicing and OTDR operators.
2. **Features.**
   - Portable.
   - AC/DC.
   - Simplex or duplex designs.
3. **Options.**
   - Cell phones.
   - Radios.

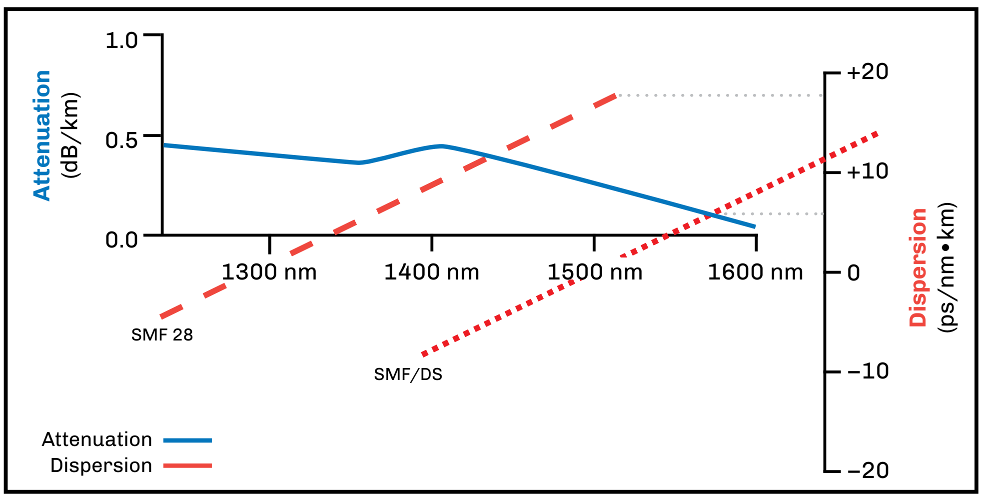
- Bidirectional voice over a single fiber
- Easy to use
- Restoration use

Optical Dispersion Testers

Optical dispersion testers measure the dispersion loss in optical fiber. Used to test single-mode fibers, the instrument measures either chromatic dispersion (CD) or polarization mode dispersion (PMD). Characterizing a fiber's dispersion is critical for verifying that an installed fiber can meet the stringent requirements of high speed and DWDM systems. An increase of a data rate of four times (e.g., 2.5 Gb/s to 10 Gb/s) creates an increase of 16 times the effect of the chromatic dispersion in a system. Both types of dispersion testing are different and require different test sets or modules to accomplish.

1. **Applications.**
   a. Measure capacity or bandwidth over fiber span.
   b. Measure in the time or frequency domain.
2. **Features.**
   a. GPIB for computer control or data collection.
   b. 1310/1550 nm single-mode laser.
   c. Transmitter/receiver pair for end-to-end measurements.

The accurate measurement of dispersion characteristics is specified by the TIA-455-175-B (formerly FOTPs 168, 169 and 175A) Measurement methods and test procedures – chromatic dispersion.



Wavelength	Dispersion
1270 nm	−3.619
1280 nm	−2.680
1290 nm	−1.423
1300 nm	−1.053
1310 nm	−0.304
1320 nm	0.547
1330 nm	1.312
1510 nm	13.789
1520 nm	14.234
1530 nm	14.826
1540 nm	15.869
1550 nm	16.357
1560 nm	16.963

- Fiber characterization testing.
  - Chromatic dispersion (CD).
  - Polarization mode dispersion (PMD).
- Measured to ensure operation at speeds greater than 2.5 Gb/s.

Chromatic Dispersion

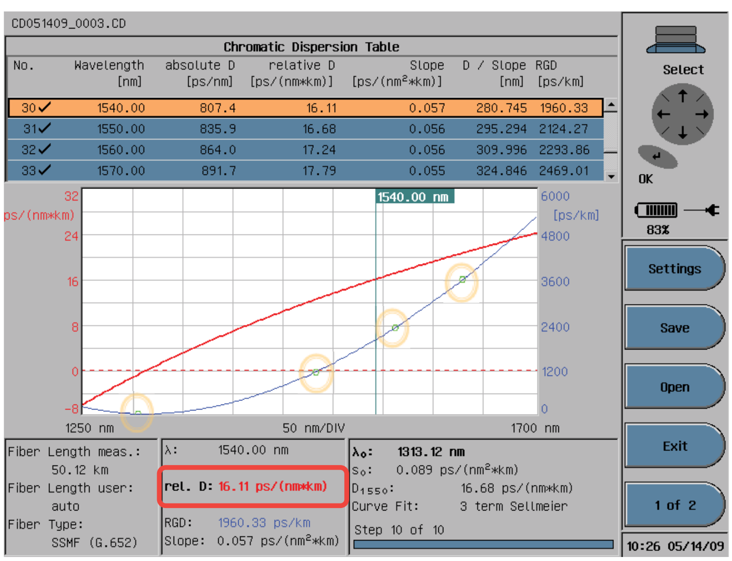
Different colors of light (wavelengths) travel at different speeds over the fiber span. In WDM, DWDM and CWDM systems, each wavelength transmitted has differing effects. Chromatic dispersion (CD) is a single-mode issue caused by:

- Material dispersion, which occurs because the speed of light varies at different wavelengths due to the optical fiber and the spectral width of the light source.
- Waveguide dispersion, which is caused by differences in the speed of light between the core and cladding in the fiber's mode field diameter.

Key Points

- Line number.
    - Pass or fail.
    - The default is set at 1000 ps/nm.
- Absolute D = total dispersion at given wavelength.
- Relative D = average per kilometer; absolute D divided by fiber length.
- Slope is the value given to DCM manufacturers to match curve fit.
- Wavelength.
    - Fiber length.
    - Fiber type.

Bit rate	Tolerable time delay @ 1550 nm	Maximum fiber distance without compensation	
		G.652 SMF	G.655 SMF
2.5 Gb/s	18.81 ns/nm	940 km	1,880 km
10 Gb/s	1,175 ps/nm	60 km	120 km
40 Gb/s	73.5 ps/nm	3.7 km	7.4 km

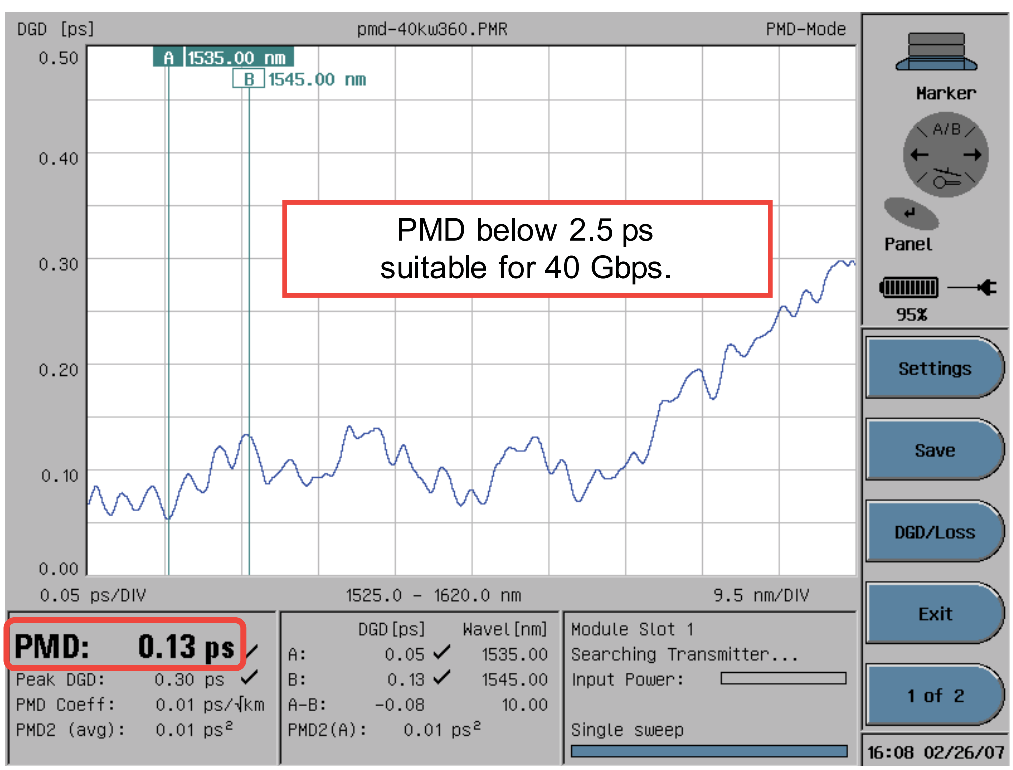


Polarization Mode Dispersion

Polarization mode dispersion (PMD) affects systems with higher bit rates (10 Gb/s and above). Single-mode fibers carry two modes with different polarization. Fibers are not perfect and slight differences in symmetry along the fiber span cause one of the modes to propagate slower than the other, resulting in pulse spreading. They can be affected by vibration, temperature, and bending.

		Maximum Link Length		
Bit Rate	**Maximum PMD**	**0.08 ps/km^2**	**0.02 ps/km^2**	**1 ps/km^2**
2.5 Gb/s	40 ps	250,000 km	40,000 km	1,600 km
10 Gb/s	10 ps	15,000 km	2,500 km	100 km
40 Gb/s	2.5 ps	1,000 km	160 km	6 km

- PMD is the average differential group delay (DGD) for the fiber span.
- Peak DGD is the worst case of group delay.
- Below 2.5 ps will work for 40 Gb/s.
- PMD coefficient = figure of merit.
- Second PMD is important if transmitting at speeds 40 Gb/s or greater.
- PMD can be caused by vibrations or thermal stresses.



Testing Documentation

Acceptance Testing

When acceptance testing a cable reel, the cable should be compared to the purchasing and engineering requirements including fiber count, length, attenuation, cable structure, plus the condition of the cable after shipping.

Performance

Once the cable has been installed it should be tested to confirm the performance versus that specified. This should occur bidirectionally at two wavelengths to measure attenuation, distance, and any losses from splices, connections, and splitters. In the case of reflective components such as connectors, the ORL level of the span and individual reflectance level of any component should be documented and compared to system requirements.

Maintenance Records

Documenting the transmit and receive optical power levels and the outside plant or premises attenuation levels provides a quick reference to how these levels have changed when testing later. Additional tests can include reflection, ORL, dispersion, or bandwidth. As-built drawings and documentation is always beneficial if kept current.

Restoration Requirements

This information can be used to assist in restorations by using previously documented and recorded OTDR traces and power levels to identify changes in spans as well as using as-built documents to identify slack locations.

Key Elements of an Effective Maintenance Posture

On-site

- Operational skill.
- Documentation (drawings and procedures).
- Elementary troubleshooting capability.
- Access to expert consultation via phone.
- Emergency restoration kit.

On-call

- Hotline.
- Standing maintenance contract.
- Experienced emergency restoration crews.
- Standby restoration equipment.
- A large inventory of restoration materials.
- Construction contracting.

Chapter 10 Review

1. What type of test equipment is used to test for total distance and provide attenuation values for fiber loss per kilometer, splice, connector, and total span loss?

2. What is a fault locator used to locate within a fiber optic network?

3. Which piece of test equipment uses a red laser light?

4. What types of tests use total fiber distance and decibels per kilometer?

5. What is a simple device used to locate faults in the OTDR deadzone?

6. What instrument is used to visually inspect fiber optic connector endfaces?

7. What function does a fiber identifier serve?

8. Are fiber identifiers effective with multimode fiber?

9. True or false: Visual fault locators verify damage in the form of light leakage.

Chapter 10 Review

10. In what mode do optical power meters measure power?

11. What two wavelengths are used when measuring multimode fiber spans?

12. What two wavelengths are used when measuring single-mode fiber spans?

13. What fiber optic test equipment is required for calibration traceable to the National Institute of Standards Technology?

Student Notes

Chapter 11

Optical Testing

By the end of this chapter, you will be able to:

- Compare and contrast Tier 1 and Tier 2 testing
- Describe various optical loss testing procedures
- Differentiate between reflective and non-reflective events on OTDR traces
- Discuss the importance of accurate and complete documentation and reporting

Fiber Optic Testing

While most single-mode or multimode fiber tests are similar, each still has particular requirements. For example, multimode testing often requires tests to meet industry specifications tailored to the premises industry and does not normally include splice and splitter testing or characterization testing.

Single-mode testing for service providers requires stricter values and requirements than most multimode tests. Stringent reflection and optical return loss (ORL) testing was necessary for reflection-sensitive Fabry-Perot and distributed feedback lasers (versus the VCSELs and LEDs used in multimode transmitters). Additionally, optical splitters are used in FTTx and hybrid fiber coax systems, but rarely in multimode systems. Due to higher speeds and much longer outside plant spans, more thorough OSP fiber tests are performed with the expectation that the fiber will be damaged in the future.

High end testing can include fiber characterization for chromatic and polarization mode dispersion, and DWDM wavelength and power measurements that require greater expertise and specialty test equipment.

Traditional Fiber Optic Testing

Test	Multimode	Single-mode
TIA-568 premises Tier 1 and Tier 2	✓	✓
Test methods – premises	✓	
Test methods – outside plant		✓
Multimode launch conditions	✓	
Not to exceed charts	✓	✓
Tx and Rx power levels	✓	✓
Tx and Rx documentation	✓	✓
Tx and Rx systems with VOA		✓
Fiber optic splitters		✓
OTDR signatures	✓	✓
OTDR forms	✓	✓
Splice loss forms	✓	✓
Documentation	✓	✓

TIA-568 Testing Terminology

In annex E of the TIA-568-C.0 standard, information is provided to ensure that installed fiber cabling in premises installations meets the following minimum requirements.

Tier 1 Testing (Required)

- Attenuation testing with an optical loss test set (OLS and OPM).
- Fiber length verification by sequential markings or a OLTS if the set has length measurement capability.
- Polarity of the installed and terminated fibers. A visual fault locator can also be used to confirm polarity.
- Multimode tested per TIA-526-14A, Method B.
- Launch conditions per TIA-455-78B (external mandrel wrap).
- Single-mode tested per TIA-526-7.
- Test method needs to be identified on test report.

Tier 2 Testing (Optional)

- OTDR testing.
- Wavelengths must match tier 1 OLTS tests.
- Segment length.
- Attenuation uniformity (slope).
- Attenuation rate (dB/km).
- Connector location and insertion loss.
- Splice location and splice loss.
- Microbend or macrobend losses and locations.

The tier 2 OTDR testing does not replace the tier 1 testing but is used for supplementary evaluation of the installed fiber optic cable link.

Cabling Subsystem 1 Link Segment: Thi s requirement in the TIA-568 standard applies between the equipment out (or MUTOA) to the horizontal cross-connect (HC) patch panel and requires that segments at a minimum need to be tested in one direction at one wavelength. Thi s would be either 850 nm or 1300 nm for multimode fibers. For single-mode fibers, it would be at either 1310 nm or 1550 nm.

Cabling Subsystem 2 and Cabling Subsystem 3 Link Segments: Subsystem 2 applies to the segment between the HC patch panel and the intermediate cross-connect (IC) patch panel. Subsystem 3 adds the link from the IC to the main cross-connect (MC). Testing both subsystem 2 and 3 link segments can occur from the HC to the MC and, at a minimum, need to be tested in one direction at two wavelengths. Th is would be 850 nm and 1300 nm for multimode fi bers, and at 1310 nm and 1550 nm for single-mode fi bers.

Test Methods

What Are You Testing and Which Test Method Should You Use?

End-to-end link loss is used by end users to determine the span loss between transmission equipment, including fiber attenuation and all connections at patch panels. The one-cord (or one-jumper) method is the most accurate loss measurement method and is recommended by most test equipment manufacturers. A test reference cord (TRC) is connected to the light source and power meter, and this power measurement is documented or "zeroed out". The TRC is then disconnected from the power meter only (do not disconnect it from the source) and a second known good TRC is connected to the power meter. The link under test is connected to via the two TRCs. The power is measured and the loss can be accurately calculated or reported by the test equipment. *Test standard: TIA-526-14B (Annex A, one-cord reference method)*

Installed cable span between patch panels includes the loss of the optical cable and terminations performed by the installers. *Test standard: TIA-526-14B (Annex C, two-cord reference method)*

This test is usually performed by the installer as they normally are responsible for the installation of the fiber optic cable, the end terminations and the mating of the connectors into the proper adaptor sleeves at patch panels. The fibers in the cables are identified by the TIA-598 color code standard and would mate to the appropriate numbered adapter ports at patch panels.

During the reference testing using two jumpers, one complete connection (two connectors and one adaptor) are zeroed or removed from the test to be performed. As the test will occur between two patch panels terminated with a connector at each end and one additional adaptor, the attenuation measured is the loss of one connection and the fiber span. This technique does not include the loss of the patch cords to be added later to terminate between the transmission equipment and the fiber span.

Cable assemblies are tested identically to item B. Tests for preterminated cable assemblies must be performed in a controlled environment. Test standard: TIA-526-14B (Annex C, two-cord reference method).

Manufacturers terminate, test, and inspect cable assemblies for bidirectional attenuation at 850 nm and 1300 nm for multimode assemblies and 1310 nm and 1550 nm for single-mode assemblies.

Installations or cable assemblies with different types of connections are tested using the three cord reference method. This method attempts to exclude the loss of the connections to the cable under test and involves three test jumpers of which one is a substitution cord. Test standards: TIA-526-14B (Annex B, three-cord reference method), TIA-568.C.0 (for channel testing), and IEC 14763-3.

In specialty applications including data centers and military/aerospace, connectors with a male (pin) and female (socket) configuration require a three-cord test.

The test requires three test reference cords (TRC1, TRC2, TRC3). TRC1 and TRC2 will be terminated with the connector matching your test equipment on one end and the connector matching the link under test on the other end. Connect TRC1 to the light source and TRC2 to the power meter. Insert TRC3, which will have the same connectors as your link under test, between TRC1 and TRC2 and document the power level. Now remove TRC3 and substitute the link under test and document the added loss.

If the end user wants to know the attenuation level between the transmitter and receiver locations, the optical power level must be measured from the transmitter (in dBm), as well as the received power level at the receiver (in dBm). The loss between the Tx and the Rx is the difference between the two power measurements (dBm minus dBm = dB).

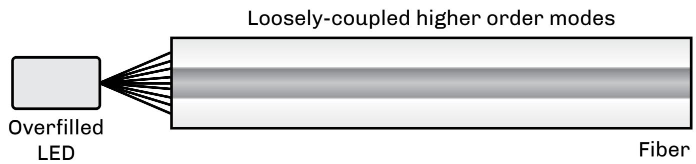
Multimode Launch Conditions

Over the years several launch condition methods have been used and identified in test standards. Multimode fiber systems can use two basic types of LEDs (edge and surface emitters) or VCSELs with different spatial spreads (low and high). This provide four different options for launch conditions coupled into any type of multimode fiber.

Following is a brief overview of the most common techniques.

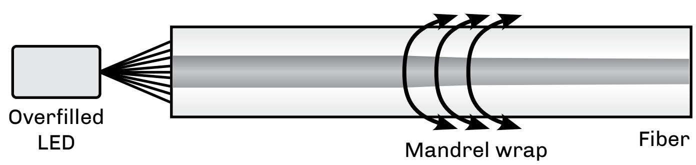
Overfilled Launch (OFL) Conditions Using an LED

This test provides the worst case launch and attenuation measurements. Due to the fact that most contractors have this type of equipment, it is the most likely to be used. This condition is based on the use of an LED light source.



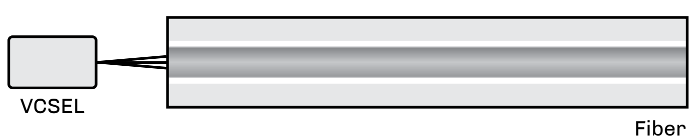
Restricted Mode Launch (RML)

More complex than the OFL launch condition, this uses an external mandrel designed for either 50/125 or 62.5/125 micron multimode fibers. RML removes higher order modes, which limit the bandwidth of the system while lowering the attenuation measurement of the fiber span. Installers easily can add a mandrel to try to match VCSEL characteristics, as specified in the TIA-455-78B FOTP, Annex A.1.3.1.2. The mandrel used must match the fiber size to be tested.



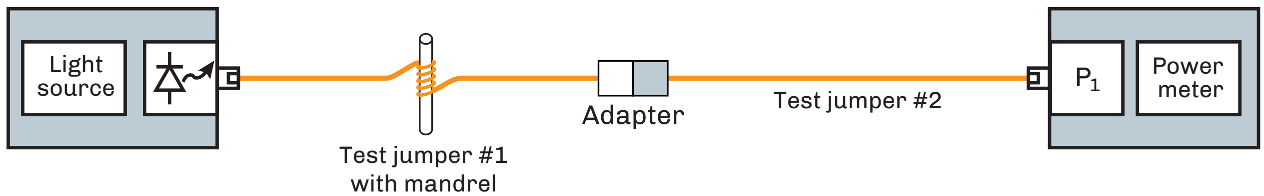
Encircled Flux (EF)

More complex and stringent than the OFL method, EF launch conditions can be achieved with an EF-compliant source mated to a specific test reference cord (TRC), or with a non-EF source connected with an EF mode conditioning launch cord.

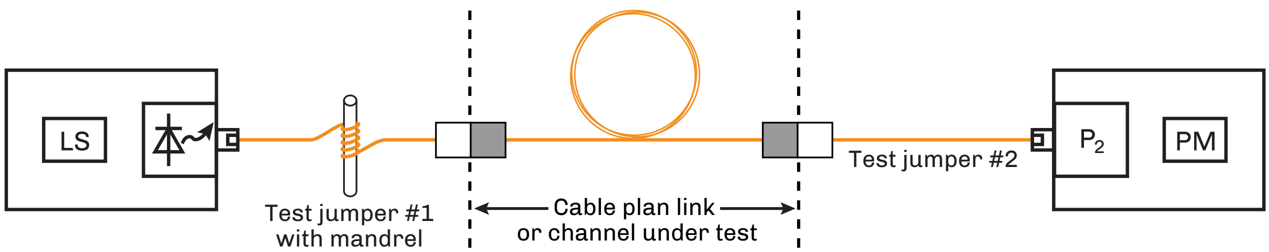


Optical Loss Testing with a Mandrel

The use of an LED when testing a multimode link is called an overfilled launch condition (OFL). The measurement obtained using this technique is the worst case measurement an installer can obtain. It is also the easiest to perform and is applicable to most light sources available.



Reference power measurements using a mandrel



Span test using a mandrel

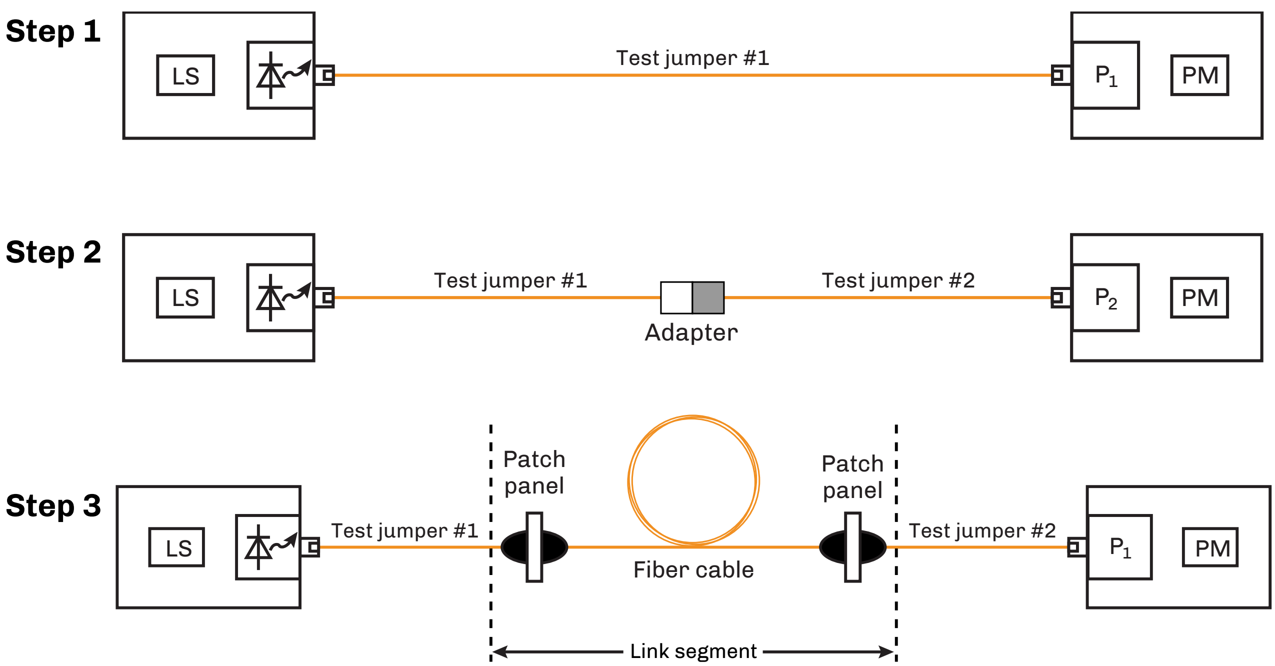
One-cord Reference Test Method

This test, performed by end users, determines the losses of both the connections normally located at patch panels at each end of the cable link to be tested. Specified by the TIA-526-14B (Annex A), the test is called a one-cord reference because only one of the two test jumpers is used for the reference. The performance of the test jumpers should be confirmed prior to link or span testing. Industry best practices recommend that specific test reference cords are used for the test jumpers. These cords are built with tighter tolerances and assure more accurate and repeatable test results.

In the following diagram you can see that two test jumpers (TJ1 and TJ2) are used at each end of the link to be tested. After confirming that the test jumpers are clean and meet the attenuation level required, TJ1 is connected to the patch panel adapter from the OLS. TJ2 is linked between the patch panel adapter and the OPM.

Note: If the test is to be performed using an overfilled launch (OFL) condition, a mandrel would be used on TJ1. For encircled flux (EF) testing where the light source has an internal restricted launch the mandrel is not required, but the appropriate test reference cord must be used with the EF compliant source.

The one-cord reference test method is recommended for multimode link testing, providing the most accurate and repeatable results. It is preferred for both multimode and single-mode testing, as specified in the TIA-568-C.0 standard.



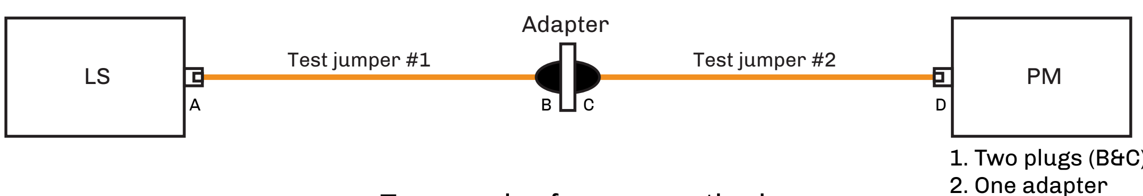
Two-cord Reference Test Method

This test method is preferred by contractors who are responsible for the installation of the optical cable and the termination of the fibers normally between two patch panels. It is also used by manufacturers of cable assemblies to measure the attenuation of cable assemblies using like terminations.

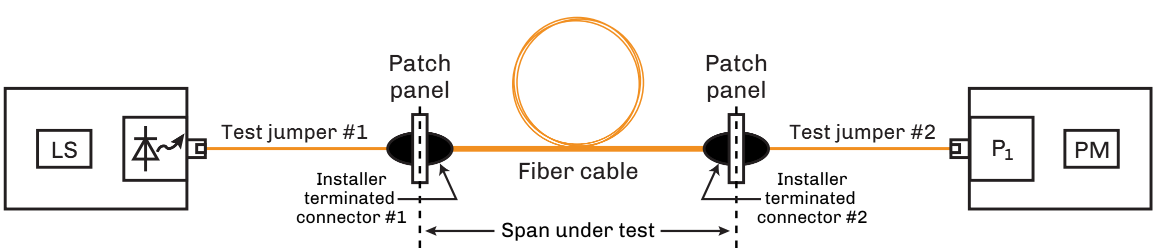
The test, specified by the TIA-526-14B (Annex C), measures the loss of the installed cable span, including the loss of the plugs terminated by the installer that are normally mated into patch panels. It requires that two test jumpers be referenced together and have their loss zeroed out by the OPM, so that any loss added between the two test jumpers is measured. This technique does not include the loss of any patch cords that are added later to terminate between the transmission equipment and the fiber span.

During the reference testing using two jumpers, one complete connection (two plugs and one adaptor) are zeroed or removed from the test to be performed. As the test will occur between two patch panels terminated with a plug at each end and one additional adaptor, the attenuation measured is the loss of one connection and the fiber span. It is this loss that is the installer's responsibility.

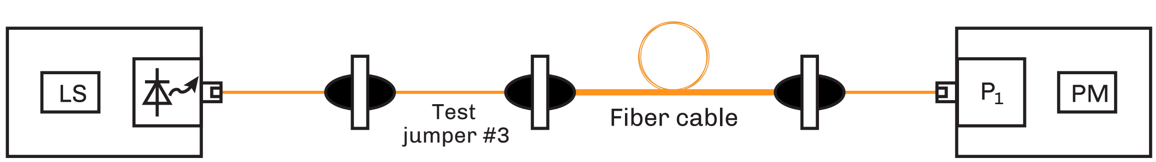
Note: If the test is to be performed on multimode fiber using an overfilled launch (OFL) condition, a mandrel would be used on TJ1. For encircled flux (EF) testing where the light source has an internal restricted launch the mandrel is not required.



Two-cord reference method



Two-cord reference span test

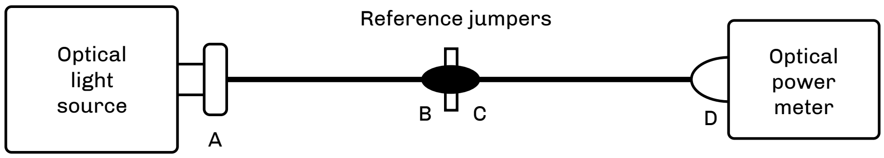


Modified two-cord reference span test

Insertion Loss Method

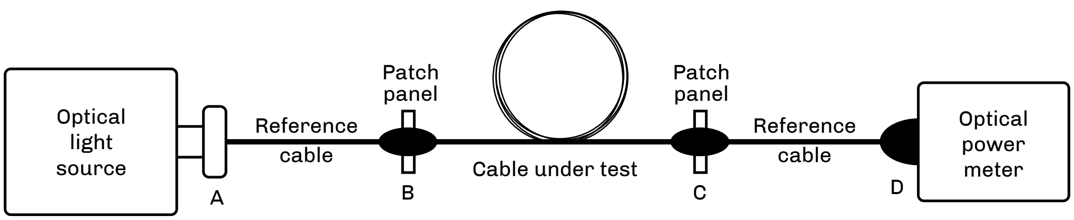
For Testing Connectorized Cables

Referencing the Test Set



1. Turn on the optical light source and allow it to stabilize.
2. Clean the optical connectors.
3. In between the light source and the optical power meter (OPM), attach the two (2) reference jumpers with connectors and polishes matching the fiber to be tested.
4. Set the power meter to the correct wavelength; record the power level (in dBm) and zero the meter to display dB on the OPM.
5. Insert the cable or span to be tested between the reference jumpers.

Inserting Cable to be Tested



1. Record the cable loss in dB and the final power measurement in dBm.
2. Repeat the test at each wavelength required.
3. Test each run in each direction.

“Not to Exceed” Chart for Multimode Spans

“Not to exceed” spreadsheets are great for installers, contractors and inspectors. They identify the total loss values of the optical cable, connectors, and splices, and help to easily pinpoint fiber spans that are out of specification. Contractors and installers normally provide optical loss testing using the stabilized light sources and calibrated optical power meter to measure the attenuation levels between the transmission equipment’s patch panels to demonstrate proof of performance. These tests normally are performed bidirectionally and at 850 nm and 1300 nm, based on TIA-568 specifications for 62.5/125 graded-index multimode fibers for a given span length.

There is also a column for the additional connection loss (see Note 1), based on performing fiber optic testing when using the insertion loss technique as specified in TIA-455-171-A, test method B (attenuation by substitution measurement), and TIA-526-14B, method A (optical power loss measurements of installed multimode fiber plant). The final measurement in this column is a “not to exceed” number in dB.

Feet	Meters	850 nm (3.5 dB/km)	With patch panel	1300 nm (1.5 dB/km)	With patch panel
100	30	0.10 dB	0.85 dB	0.05 dB	0.80 dB
200	61	0.21 dB	0.96 dB	0.10 dB	0.85 dB
300	91	0.32 dB	1.07 dB	0.14 dB	0.89 dB
400	122	0.42 dB	1.17 dB	0.19 dB	0.94 dB
500	152	0.53 dB	1.28 dB	0.23 dB	0.98 dB
600	183	0.65 dB	1.40 dB	0.28 dB	1.03 dB
700	213	0.74 dB	1.49 dB	0.32 dB	1.07 dB
800	244	0.85 dB	1.60 dB	0.37 dB	1.12 dB
900	274	0.97 dB	1.72 dB	0.42 dB	1.17 dB
1000	305	1.06 dB	1.81 dB	0.46 dB	1.21 dB
1250	381	1.34 dB	2.09 dB	0.58 dB	1.33 dB
1500	457	1.59 dB	2.34 dB	0.69 dB	1.44 dB
1750	533	1.84 dB	2.59 dB	0.80 dB	1.55 dB
2000	610	2.18 dB	2.93 dB	0.92 dB	1.67 dB
2500	762	2.69 dB	3.44 dB	1.15 dB	1.90 dB
3000	914	3.21 dB	3.96 dB	1.38 dB	2.13 dB
3281	1000	3.50 dB	4.25 dB	1.50 dB	2.25 dB
4000	1219	4.27 dB	5.02 dB	1.83 dB	2.58 dB
5000	1524	5.38 dB	6.13 dB	2.29 dB	3.04 dB
5280	1609	5.64 dB	6.39 dB	2.42 dB	3.17 dB

Notes:

1. Attenuation numbers are rounded to the highest 1/100th of a dB.
2. With patch panel column includes additional 0.75 dB as specified in TIA-568 for connection not included in light source and power meter reference using two reference jumpers and additional sleeve.

"Not to Exceed" Chart for Single-mode Spans

"Not to exceed" spreadsheets are great for installers, contractors, and inspectors. They identify the total loss values of the optical cable, fiber, connectors, splices, and splitters, and help to easily pinpoint fiber spans that are out of specification. Contractors and installers normally provide optical loss testing using the stabilized light sources and calibrated optical power meter to measure the attenuation levels between the transmission equipment's patch panels to demonstrate proof of performance. These tests normally are performed bidirectionally and at 1310 nm and 1550 nm. In single-mode systems these tests also are performed using the OTDR.

Based on generic specifications for G.652 single-mode fibers for a given span length for 1310-nm and 1550-nm wavelength-based systems.

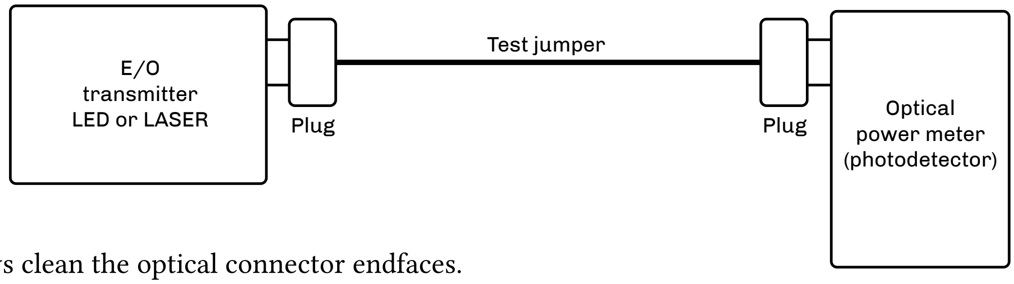
In addition, a column has been added for the additional connection loss (1) based on performing fiber optic testing when using the insertion loss technique as specified in TIA-455-171-A, test method B (attenuation by substitution measurement) in this column is a "not to exceed" number in dB.

km	1310 nm (0.4 dB/km)	+ Splice qty x 0.1 dB	With patch panel	Total	1550 nm (0.25 dB/km)	+ Splice qty x 0.1 dB	With patch panel	Total
1	0.4	0.2	0.5	1.15	0.25	0.2	0.5	0.95
2	0.8	0.2	0.5	1.50	0.50	0.2	0.5	1.30
3	1.2	0.2	0.5	1.90	0.75	0.2	0.5	1.45
4	1.6	0.2	0.5	2.30	1.00	0.2	0.5	1.70
5	2.0	0.2	0.5	2.70	1.25	0.2	0.5	1.95
10	4.0	0.3	0.5	4.80	2.50	0.3	0.5	3.30
15	6.0	0.4	0.5	6.90	3.75	0.4	0.5	4.65
20	8.0	0.5	0.5	9.00	5.00	0.5	0.5	6.00
25	10.0	0.6	0.5	11.10	6.25	0.6	0.5	7.35
30	12.0	0.6	0.5	13.10	7.50	0.6	0.5	8.60
35	14.0	0.7	0.5	15.20	8.75	0.7	0.5	9.95
40	16.0	0.8	0.5	17.30	10.00	0.8	0.5	11.30
45	18.0	0.9	0.5	19.40	11.25	0.9	0.5	12.65
50	20.0	1.0	0.5	21.50	12.50	1.0	0.5	14.00
55	22.0	1.0	0.5	23.50	13.75	1.0	0.5	15.25
60	24.0	1.1	0.5	25.60	15.00	1.1	0.5	16.60
70	28.0	1.3	0.5	29.80	17.50	1.3	0.5	19.30
80	32.0	1.4	0.5	33.90	20.00	1.4	0.5	21.10
90	36.0	1.5	0.5	38.00	22.50	1.5	0.5	24.50
100	40.0	1.7	0.5	42.20	25.00	1.7	0.5	27.20

Notes:

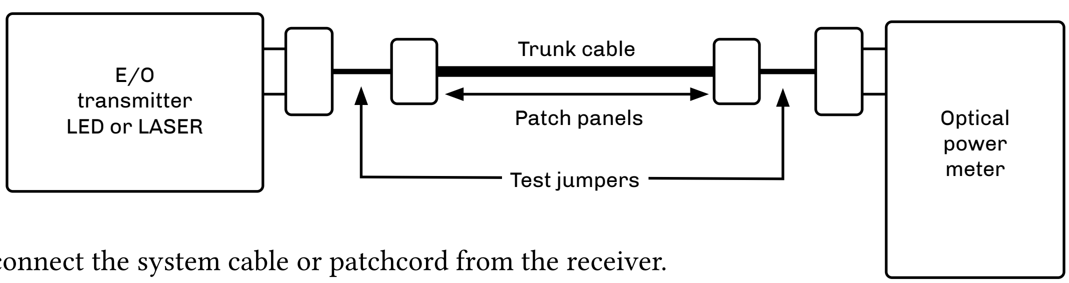
1. Attenuation numbers are rounded to the highest 1/100th of a dB.
2. With patch panel column includes additional 0.5 dB as specified in ITU-T G.671 for connection not included in light source and power meter reference using two reference jumpers and additional sleeve.
3. Adjust splice loss to meet your requirements. Column is based on 0.1 dB/splice as specified in the Telcordia GR-20 and outside plant standard.
4. Based on the inclusion of two pigtail splices and 6-km cable spans.

Testing Transmitter Output Power



1. Always clean the optical connector endfaces.
2. Connect a test cable with known loss between the transmitter and the optical power meter.
3. Set the optical light source to correct wavelength.
4. Set the power meter to watts or dBm setting.
5. Turn the transmitter on and allow it to stabilize.
6. Record the optical power displayed on the optical power meter.
7. Subtract the loss of the test jumper for the output power of transmitter.
8. Document into the transmitter acceptance test report. Confirm that the transmitter meets specification.
9. Refer to the system manual to confirm that the measurement is above minimum acceptable coupled power.
10. For maintenance and troubleshooting, follow steps #1 through #7 and compare the new measurements to that recorded in item #8.

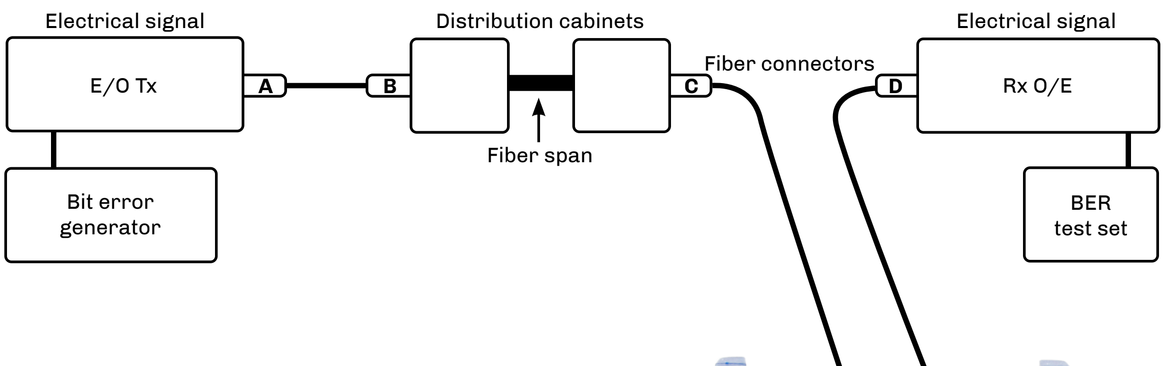
Testing Receiver Input Power



1. Disconnect the system cable or patchcord from the receiver.
2. Always clean the optical connector endfaces.
3. Connect the optical cable to the power meter.
4. Set the optical power meter to the correct wavelength.
5. Turn on the transmitter.
6. Record the optical power (dBm).
7. Refer to the outside plant acceptance or maintenance report for comparison.
8. Refer to the system manual to confirm that the power level is above minimum acceptable receiver power and below maximum receiver power level.
9. If the power level is too high and oversaturates the photodiode, a fixed attenuator may be required at the receiver.

Optical Fiber Transmission System

Testing with Variable Optical Attenuator and Optical Power Meter



1. With the system in its installed and final configuration, attach a bit error generator to the transmitter and a bit error rate (BER) test set to the receiver. Insert a variable optical attenuator (VOA) in front of the receiver with the attenuation set to 0.0 dB and turn the system on.
2. Verify that the system is running error free by inserting errors at the transmitter and verifying the receipt of the errors at the receiver.
3. Slowly add attenuation into the system with the VOA while watching the BER test set. When the bit error rate reaches an unacceptable level (degraded service and out of service), read the amount of attenuation (dB) or power level (dBm) that had to be added.
4. This amount of attenuation is the system margin. This is the amount of attenuation that the system can absorb before it fails.

Notes:

1. Air-gap attenuators should not be used for multimode fiber due to the possibility of modal noise when used in conjunction with laser transmitters.
2. All VOAs have some attenuation. This value should be calculated into the final measurement.

Transmitter and Receiver Documentation

Operator	Date
Location A	Location B
Connector/polish	Fiber type
Power meter	Wavelength

Fiber	Tx level (dBm)	Rx level (dBm)	Min Rx level (dBm)	Tx – Rx = dB
1				
2				
3				
4				
5				
6				
7				
8				

This form allows for pre- (planned) or post- (unplanned) acceptance testing or performance testing of transmission systems. For acceptance testing, the transmitter and receiver are linked using two optical jumpers that match the fiber type and connectors used in the system. In both acceptance testing and hot testing of transmission equipment, a performance test set is required to test signal quality. BERT or datacom analyzers are two types of equipment used to test signal quality.

Step 1. Measure the output power (dBm) using a power meter calibrated to the correct wavelength. Record in column B. Compare to manufacturer's specifications.

Step 2. Disconnect the jumper from the receiver and measure the received power (dBm). Document and list in column C.

Step 3. Insert a variable optical attenuator (VOA) with known excess loss (when measuring 0 dB) between the transmitter and receiver (or between the receiver and patch panel. Make sure that the fiber jumpers and the calibration wavelength of the VOA match the system. Increase the signal loss with the VOA until the system's performance degrades below the minimum acceptable level.

Step 4. Disconnect the jumper from the receiver port and measure the received power (dBm) using the optical power meter. Record this measurement into column D.

Note: The difference between power levels in column B (dBm) and C (dBm) equals the loss in dB (column E). This is the existing loss. The difference between columns B and D is the maximum allowed loss without signal or performance degradation.

OTDR Deadzone

The deadzone is the area in which an OTDR cannot make measurements. It is limited by the pulse width of the laser, the reflection of the front-panel connection and the bandwidth of the receiver (detector). The deadzone cannot be shorter than the sampling distance programmed into the instrument. OTDRs constantly compromise between dynamic range and deadzone. When one improves, the other degrades. Techniques such as optical masking are an exception to this rule.

Considerations when selecting an OTDR for close measurements include the type of measurement being made, the strength of the reflection, and the OTDR's bandwidth. There are two types of deadzone:

- **Event deadzone** – Sometimes called two-point spatial resolution, it is the minimum distance after a reflection in which an OTDR can accurately measure the distance to a second event. Because this measurement is determined from the leading edge of the reflection and the 3 dB drop from the top of the reflection, this number is not to be used for determining two-point loss.
- **Deadzone loss** – This is the minimum distance **after** a reflective event before an OTDR can accurately measure a nonreflective event.

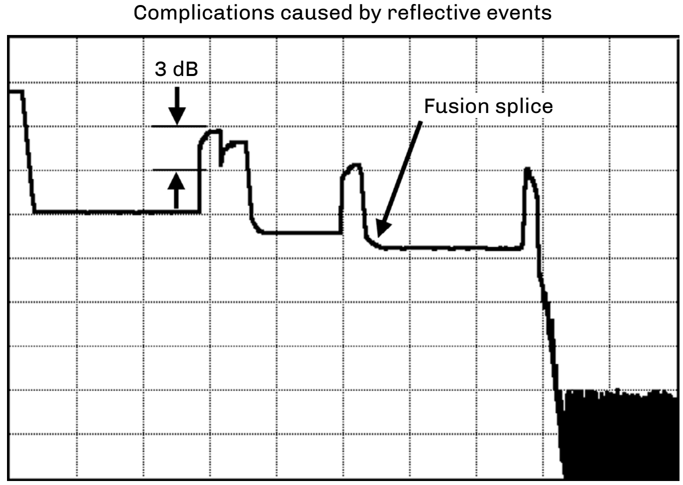
Masking

Optical masking uses a fast optical switch (electro-optic or acousto-optic) in the return leg of the OTDR (between the coupler and the receiver) to mask the intense Fresnel reflection. The application is when two events, the first of which is reflective, have a tail from the amplifier's response covering a nonreflective splice. The operator would place one marker (cursor) at the front edge and the other at the rear edge (peak) of the reflective event. This would eliminate the tail, allowing for closer measurements of the second nonreflective event. The deadzone is still limited by the pulse width, but it is much shorter without the tail.

Measuring Reflectance with a Deadzone Box

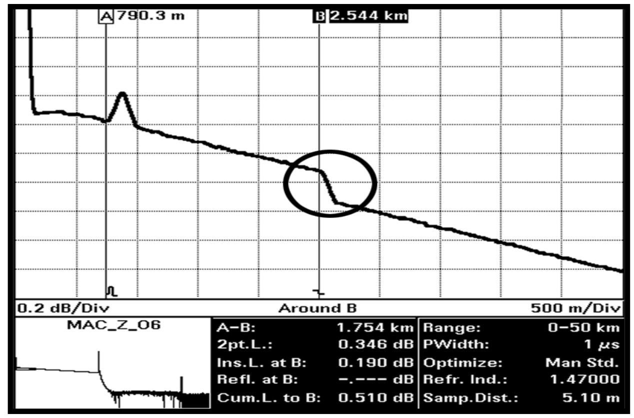
Testing for front-panel attenuation, reflectance, and the span's optical return loss (ORL) requires a deadzone box with a connector and polish that match the connector under test. The far-end connector's reflectance is tested using an optical terminator with matching polish and connector type, or a second deadzone box.

Complications caused by reflective events



Event and loss deadzone
This OTDR waveform was acquired at 1310 nm.

OTDR Signatures



Nonreflective

- Fusion splices
- Fused biconical tapered splitters
- Macro and microbends

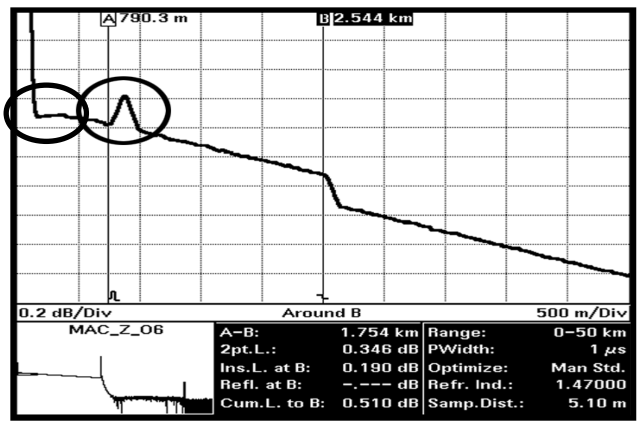
This signature is caused by a nonreflective loss of signal. The three common causes are the fusion splice, where the two fibers are melted together causing a low loss in signal or the macrobend and microbend, where the fibers are bent or pinched, causing light to escape from the fiber. The **B** marker is the correct location of the cursor placement.

Reflective

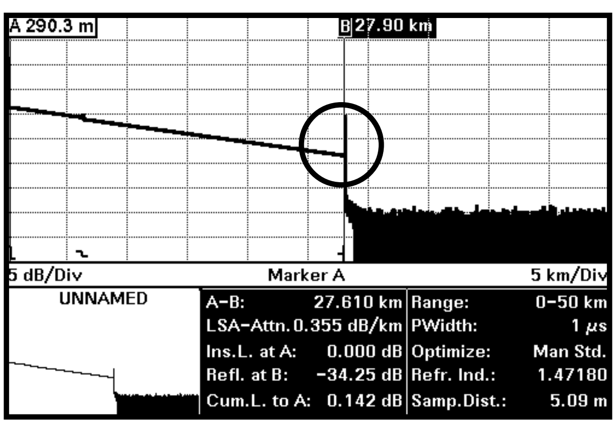
- Connectors
- Mechanical splices
- End of fiber span

The reflective spike is caused by any surface that returns a reflection to the OTDR. Reflective signatures are caused by connectors, mechanical splices, and fiber ends and are called Fresnel reflections.

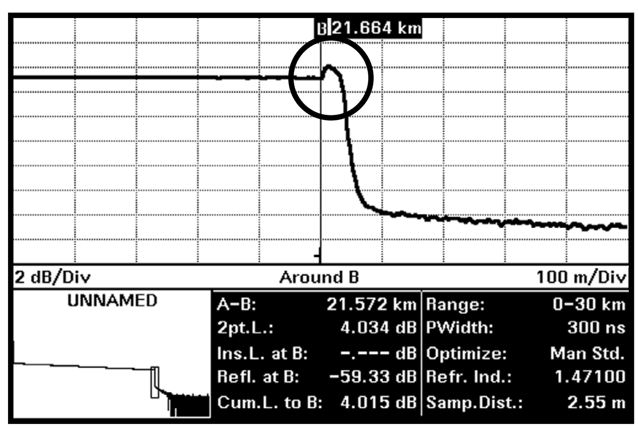
Note: When measuring a span's optical return loss (ORL), make sure that the OTDR is operating in the ORL mode. The vertical dB scale is not used to measure reflection values. In the graphics below, this OTDR manufacturer refers to ORL as "Refl." (reflection) and measures it at the cursor that is highlighted.



OTDR trace with two reflective signatures
The Fresnel reflection at the left is caused by the OTDR's front-panel connection. A lower-reflectance mechanical splice, which has an internal index matching gel, is located at the A marker.

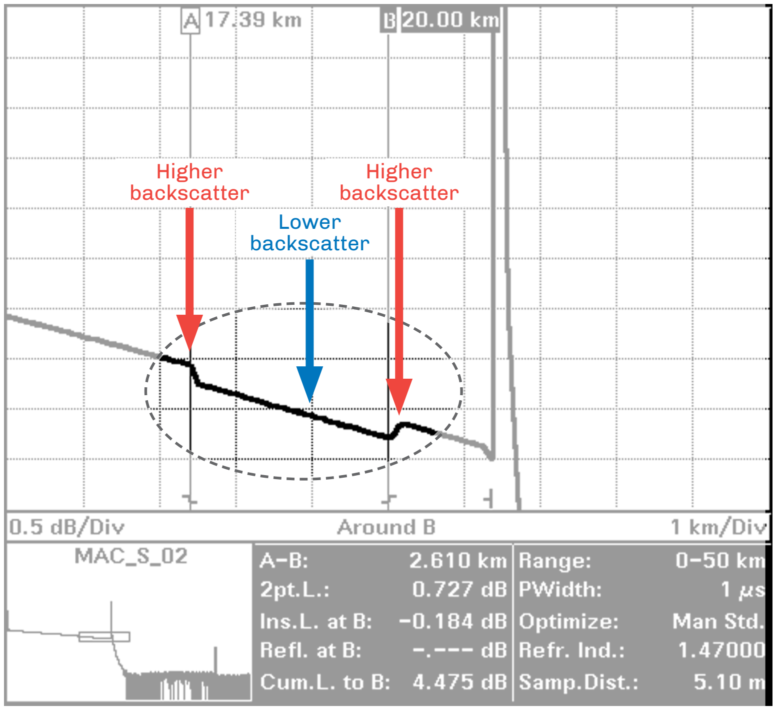


OTDR trace showing an unterminated fiber (with –34.25 dB reflection)



OTDR trace showing a fiber terminated with UPC connector (with –59 dB reflection)

Gainers on OTDR Traces



The OTDR trace shows a splice loss followed by an apparent gain at a splice point. A splice gain is a measurement artifact common on OTDR traces. There is no actual gain. When reporting splice loss, the OTDR makes the assumption that all fiber segments have the same backscatter capture coefficient, “K”, which can be a default or user entered. Typical values are −79 to −81 dB for standard G.652 fiber.

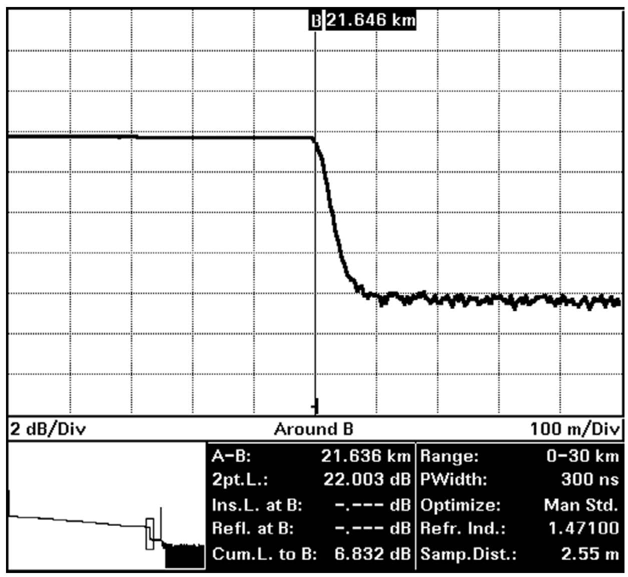
Different fiber types — even similar types from the same manufacturer — may have small variations in K (ratio of backscatter captured). This can affect the apparent splice loss reported on the trace. If the downstream fiber has a higher K, and the difference is greater the actual splice loss, then the OTDR may report a gainer. These are usually very small, and may be small enough to be accepted in a one-way OTDR test.

If the actual splice loss must be known to greater accuracy, then testing bidirectionally and averaging reported splice losses will yield more accurate values. This is because the backscatter change reverses sign in the opposite direction while the splice loss is actually the same in both directions.

Fiber Roll-off

The trace of a fiber that gradually rolls off is the signature of a nonreflective broken fiber. The signature is common in cables where water or cable gel has created a nonreflective surface after a break. Since this break is usually poor, the optical signal is dispersed and does not have the power to return to the source.

Fiber measurements should be made with the distance marker located at the point where the roll-off occurs. From this location, the distance equal to the operating pulse width must be subtracted to accurately locate the failure. The pulse width may vary with instruments, so it is best to check your operating manual for confirmation.



Example of nonreflective loss

Causes of Fiber Roll-off

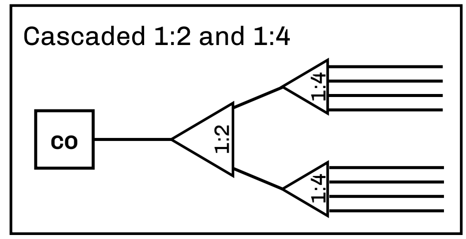
- Breaks (fractured fiber).
- Extreme macrobend.
- Fractured fiber with gel surrounding the end.
- Fractured fiber with moisture (water) surrounding the end.

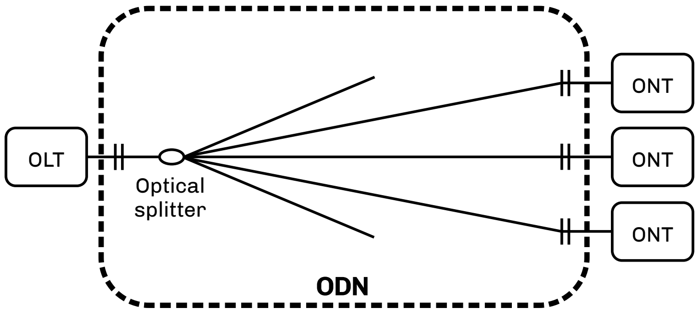
When testing a suspected break with the OTDR, it is important to confirm that the fiber is actually broken. Extreme macrobends can look like a roll-off signature, yet the cable's internal fibers are still intact. To verify, put the OTDR into real-time mode and check all the dark fibers in the span. Once a fiber is identified with a Fresnel (reflective) signature, then we have a confirmation of a fiber break.

The second advantage of this technique is that once a Fresnel reflection is located, it is easier to accurately place the OTDR's distance cursor at the actual location of the break. Whenever possible, the OTDR operator should use the last splice location (closest to the fault) in the span to measure the distance to the fault. This will be more accurate than if done from the longer distance to the test equipment location, due to the differences in the fiber length versus the cable length in cable structures.

Testing Fiber Optic Splitters

Fiber optic splitters (couplers) allow for cost savings in many networks. Testing spans with splitters requires power levels and loss measurements from each transmitter to each shared receiver. If testing transmit and receive FTTx power levels, the optical power meter must perform in-line handshaking for upstream measurements.

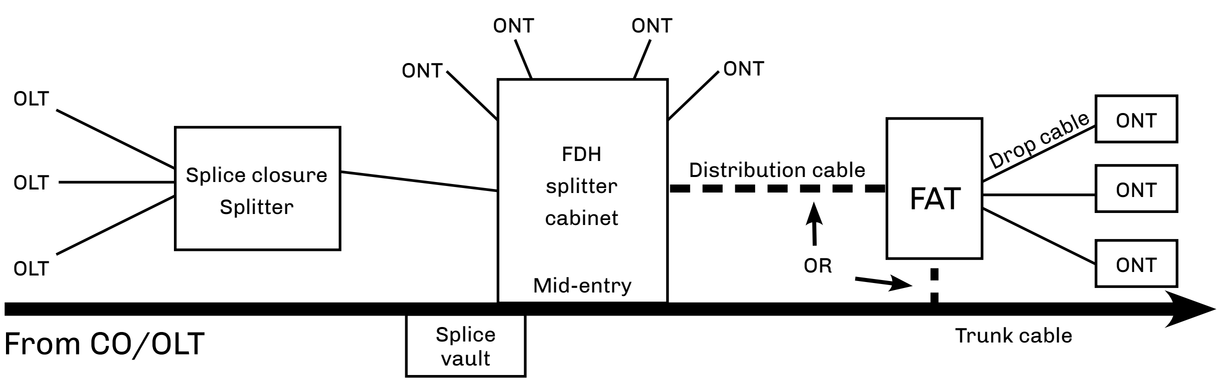




ODN — Optical distribution network
OLT — Optical line terminal
ONT — Optical network terminal

Testing Through Optical Splitters

Point-to-point insertion loss testing through fully-installed, long-haul networks measures the three basic components of a fiber optic system: connectors, splices, and the optical fiber. With the inclusion of optical splitters, the fiber plant expands from a single point-to-point system to a point-to-multipoint network. This not only includes attenuations from the components above, but also the higher loss of the splitter(s). One example would be if a network installation had a 1:4 splitter installed, approximately 6-7 dB of attenuation would be measured along with the components of the OSP for each of the four legs completed. A 1:32 splitter would incur 15.8 dB of attenuation.



Key Points to Understanding IOR

- Index of refraction (IOR) is the ratio of the speed of light in a vacuum as compared to the fiber and is used to calibrate the OTDR to the fiber under test.
- OTDRs measure fiber length, not cable length. The technician must compensate for additional fiber length by using the sequential cable markings to acquire correct cable length.
- To accurately calibrate the OTDR, the technician must know the fiber size and type, the wavelength, and the manufacturer of the fiber.

Index of Refraction

Index of refraction is the ratio of the velocity of light in a vacuum to the velocity of light in a refractive material for a given wavelength.

If light travels 186,291 miles per second in space (vacuum) and 126,642 in a single-mode fiber (at 1310 nm), then the ratio would be 1.471. The fact that the light travels at different speeds is important to understand. In fiber, the speed varies depending upon the construction of the type of glass and the wavelength of the light being transmitted. For multimode fiber, group mode velocity defines the average mode due to the multiple modes being transmitted.

Does My OTDR Accurately Measure the Length of the Cable Being Tested?

Probably not. The IOR numbers given to end users come from the fiber manufacturers, and not the cable manufacturers. There is a great amount of difference when measuring a single fiber on a fiber spool versus inside an optical cable.

There are three major reasons why fiber lengths don't match cable lengths.

1. **Fiber lay inside a loose tube buffer**.
   - You will notice that the fiber length is actually longer than the buffer tube itself. This allows the cable and buffer tube to expand and contract without stressing the internal fiber.
2. **Buffer tubes wrapping around internal cables**.
   - Buffer tubes do not lay lengthwise down an optical cable but spiral instead. First they will all spiral in one direction (clockwise) and periodically will reverse (counterclockwise). This extra length of buffer tube versus the cable jacket (sheath) length adds an additional variation in the fiber versus cable length.
3. **Inner and outer rows of buffer tubes**.
   - When fiber counts within the cable exceed 72 fibers (six tubes with 12 fibers each), there is a high chance that the cable design is one provided in multiple rows of buffer tubes in both inner and outer positions. The inner row has less wrapping and total length, whereas the outer row must have larger wraps. Therefore, the internal fiber must be longer than those in the internal row. This requires extreme detailing on records. The inner layer fibers will be shorter and therefore use a different IOR. These must be traced to the correct patch panel connectors.

Key Points to Understanding IOR

(Continued)

How Do I Resolve This?

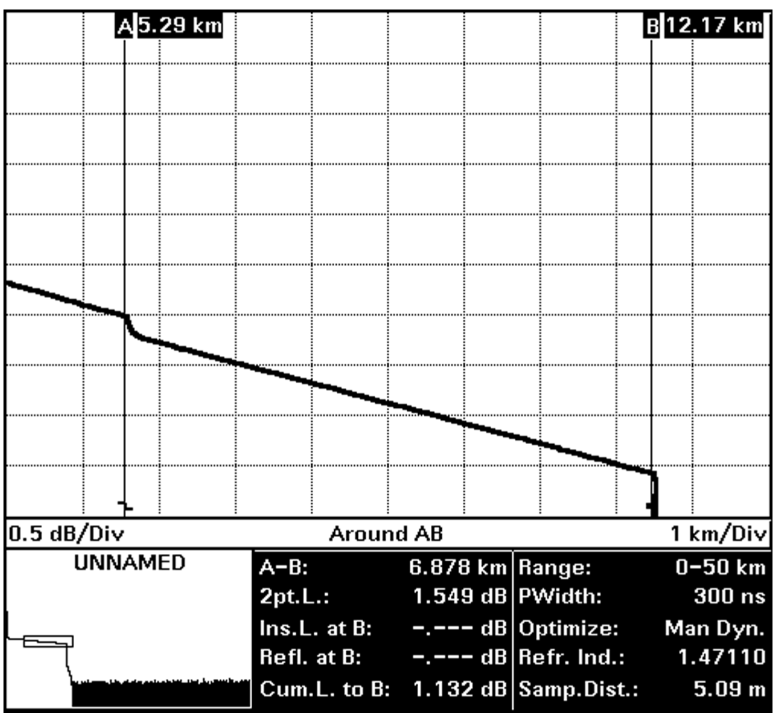
This is resolved with the proper acceptance testing of a reel of cable. By testing the cable with an OTDR, you are in a position to change the factory IOR settings to those that will match the cable jacket's sequential markings.

For example, if the documentation specifies 1.471 at 1310 nm and the shipping documentation on the reel shows the cable length to be 5,000 meters, the OTDR would measure the length at approximately 5,150 meters, assuming a 3% variation in fiber length.

Now check the sequential markings on the cable. If the difference measures to be 5,004 meters, then the IOR (which controls the timing) must be adjusted on the OTDR to compensate for the actual cable length versus the actual fiber length. In this case, we would increase the IOR until the OTDR length matches that of the cable under test. Remember the OTDR will measure from the instrument's front panel, unless programmed otherwise.

Also remember to check both inner and outer layers for different CIR (cable index of refraction) settings. These recordings should be noted in any maintenance and restoration plans for more accurate locates.

How else can you increase accuracy? Through better documentation titled "as-builts" or "as-built drawings." These will identify a sequential marking on a cable to a fixed geographic point. If a cable has been damaged 2,000 meters from the fourth splice point in a span, it is far easier to measure (using a two-point technique) from the last (known) splice point to the fault than from the patch panel to the fault.



Recommendation: In restorations, measure to the fault from the last known splice point using the two-point method (A–B). In this case, the distance is 6,878 meters.

Accuracy also includes factors such as distance so the closer to a known point the better. Another way to address this is to question which is more accurate: 1% at 2,000 meters, or 1% from 19,000 meters?

Multimode IOR Accuracy Settings

These values are given for general reference. Always check with your fiber manufacturer for current specifications.

Manufacturer	Name	IEC	Size	850 nm	1300 nm
Alcatel	Gigalite		62.5/125	1.497	1.492
	Gigalite		50/125	1.482	1.480
Corning	ClearCurve	OM2/3/4	50/125	1.480	1.479
	SX+	OM2	50/125	1.496	1.491
	eSX+	OM3	50/125	1.481	1.476
	Infinicor 300	OM1	62.5/125	1.496	1.491
	Infinicor 600	OM2	50/125	1.481	1.476
	Infinicor CL 1000	OM1	62.5/125	1.496	1.491
OFS	Standard	OM2	50/125	1.483	1.479
	Laser Wave G+	OM2	50/125	1.483	1.479
	Standard	OM1	62.5/125	1.492	1.488
	GigaGuide	OM1	62.5/125	1.496	1.491
	BFO4432		100/140	1.497	1.492
Prysmian/Draka	Max Cap	OM2/3/4	50/125	1.482	1.477
	Hi-Cap	OM1	62.5/125	1.496	1.491
Sumitomo	Standard		50/125	1.484	1.479
	Standard		62.5/125	1.496	1.491

Accuracy as a Measurement of Index of Refraction

Distance / IOR	1.471	1.472	1.461
100 feet	100 feet (0 feet)	100 feet (0 feet)	101 feet (1 foot)
500 feet	500 feet (0 feet)	499 feet (−1 foot)	503 feet (3 feet)
1,000 feet	1,000 feet (0 feet)	999 feet (−1 foot)	1,006 feet (6 feet)
2,500 feet	2,500 feet (0 feet)	2,498 feet (−2 feet)	2,517 feet (17 feet)
5,000 feet	5,000 feet (0 feet)	4,996 feet (−4 feet)	5,034 feet (34 feet)
7,500 feet	7,500 feet (0 feet)	7,495 feet (−5 feet)	7,552 feet (52 feet)
10,000 feet	10,000 feet (0 feet)	9,993 feet (−7 feet)	10,068 feet (68 feet)
20,000 feet	20,000 feet (0 feet)	19,987 feet (−13 feet)	20,137 feet (137 feet)
30,000 feet	30,000 feet (0 feet)	29,980 feet (−20 feet)	30,206 feet (206 feet)

Notes:

1. Instrument was calibrated at 1.471 and measurements were made at other settings to demonstrate accuracy from one IOR to another. The wavelength tested was at 850-nm multimode.
2. Contact your manufacturer or test reports for the proper multimode IOR.
3. Different wavelengths have different IOR because they travel at different speeds through the glass.

Single-mode IOR Accuracy Settings

These values are for general reference. Always check with your fiber manufacturer for current specifications.

Manufacturer	Name	ITU	1310 nm	1550 nm	1625 nm
Corning	SMF-28e+	G.652D	1.467	1.468	–
	SMF-28e+ LL	G.652D	1.467	1.468	–
	SMF-28 ULL	G.652	1.467	1.468	–
	Leaf	G.655	1.468	1.469	–
OFS	AllWave ZWP	G.652D	1.467	1.468	1.468
	TruWave Reach	G.655	1.471	1.470	1.470
	TruWave RS LWP	G.655	1.471	1.470	1.470
	AllWave Flex	G.657	1.467	1.468	–
	AllWave Flex+	G.657	1.467	1.468	–
Prysmian/Draka	ESMF	G.652D	1.467	1.468	1.468
	Teralight	G.655	1.468	1.468	–
	Teralight Ultra	G.655	1.468	1.468	–
	BendBright	G.657	1.467	1.468	1.468
	BendBright Elite	G.657	1.467	1.467	1.468
	BendBright XS	G.657	1.467	1.467	1.468
Sterlite	OH-LITE	G.652D	1.467	1.4675	1.468
	DOF-LITE	G.655	–	1.470	–
	BOW-LITE	G.657	1.4678	1.4685	1.4689
Sumitomo	PureAdvance	G.652	1.462	1.462	1.462
	PureBand	G.652D	1.466	1.467	1.470
	PureAccess	G.657	1.466	1.467	–
	PureAccess-R5	G.657	1.467	1.468	1.469
	PureAccess-A2	G.657	1.466	1.467	1.470

Accuracy as a Measurement of Index of Refraction

	1.471	1.472	1.481
1 km variance	1,000 m – 0 –	998 m −2 m	992 m −8 m
5 km variance	5,000 m – 0 –	4,995 m −5 m	4,966 m −34 m
10 km variance	10,000 m – 0 –	9,993 m −7 m	9,934 m −66 m
20 km variance	20,000 m – 0 –	19,985 m −15 m	19,865 m −135 m
30 km variance	30,000 m – 0 –	29,978 m −22 m	29,796 m −204 m
40 km variance	40,000 m – 0 –	39,978 m −27 m	39,730 m −270 m
50 km variance	50,000 m – 0 –	49,966 m −34 m	49,644 m −366 m

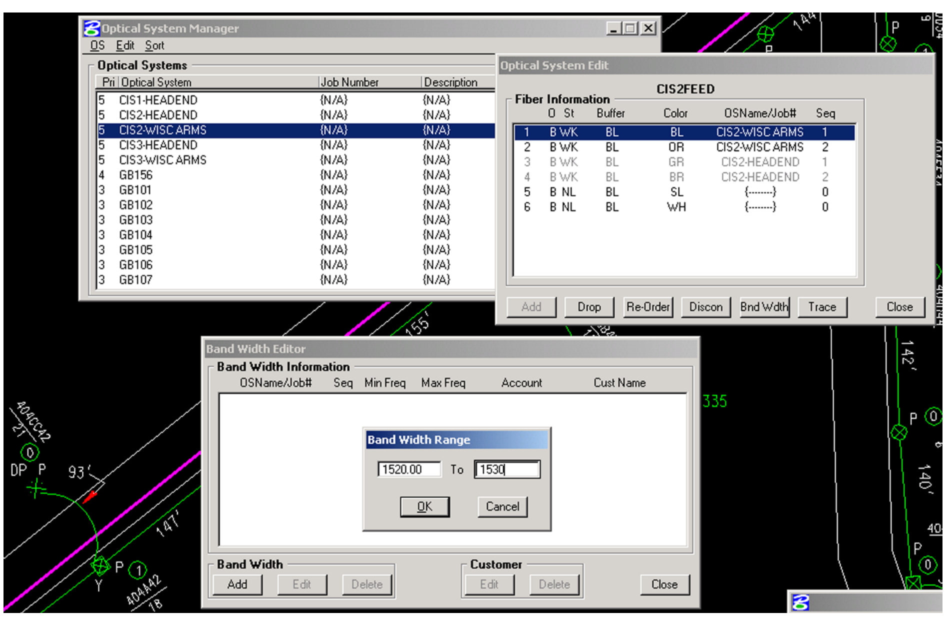
Notes:

1. Instrument was calibrated at 1.471 and measurements were made at other settings to demonstrate accuracy from one IOR to another. The wavelength tested was at 1310-nm single-mode.
2. The IOR numbers above are for single-mode fibers. Contact your fiber manufacturer or examine the manufacturer's test reports for the proper single-mode IOR.

Documentation Issues

For Emergency Restorations

- Develop a restoration plan during OSP system design.
- Compile a final "as-built" report.
- Acquire cable data manual (supplied by cable manufacturer).
- Cable manufacturer.
    - Fiber manufacturer and type.
    - Index of refraction (IOR).
    - Optical performance (OTDR prints).
    - Bandwidth/dispersion data.
    - Traceability.
    - Date of installation.
- Determine routing plan for cable.
- Prioritize circuits.
- Create attenuation report (optical loss test report).
- Conversion factors for feet/meters-kilometers.
- Prepare bill of materials for emergency restoration kit.
    - Material list.
    - Ordering information.
    - Date coded issues.
    - Instructions.



Chapter 11 Review

1. What should be done to all connectors before testing?

2. What type of light sources are used to test LANs for OM1 and OM2 fibers?

3. What type of light sources are used to test LANs for OM3 and OM4 fibers?

4. True or false: "Not to exceed" charts help to quickly determine if the total loss of the span meets the required end-to-end loss specifications and individual component values.

5. How will a mechanical splice or a connector show up on the OTDR display?

6. What type of OTDR measurements require the correct fiber index of refraction value?

7. True or false: The OTDR measures cable length.

8. What is the difference between optical return loss (ORL) and reflectance?

9. What type of test equipment can measure both ORL and reflectance?

10. What is the only thing a continuity tester tests for in optical fibers?

Chapter 11 Review

11. What are the different launch conditions and methods used to perform multimode attenuation tests?

12. True or false: The five common settings on an OTDR that should be set up properly are range, average time, pulse width, index of refraction, and proper marker placement.

13. What is a deadzone?

14. How can attenuation and reflection measurements be made with an OTDR?

15. True or false: Optical loss test sets are the only test equipment that truly measure end-to-end loss.

Student Notes

Chapter 12

Restoration

By the end of this chapter, you will be able to:

- Describe the differences between a restoration plan and a maintenance posture
- List the consumables that should be kept on hand for a restoration
- Compare and contrast nonretrievable and retrievable slack scenarios

Identify – Locate – Resolve

Murphy's Law on Cable Restoration

Cable failure will happen at the worst possible time,
at the worst conceivable location.

Planning and preparation are key.

Planning for a fiber optic outage should be part of any design plan. Whether your fiber link is indoors, outdoors, or both, the potential for an outage exists. The primary design goal is to minimize disruptions and to develop a plan on how temporary and permanent repairs would take place in a logical sequence. The plan should take into consideration the physical location of the cable, safe access to the cable, whether retrievable slack is available, and the staff and equipment requirements.

Communication cables that are damaged also have historical data available. It doesn't matter if the cable is copper, coax, or fiber, many outages are caused by similar events, such as vehicles, weather, rodents, dig-ups, lightning, and flooding, to mention a few. Outages occur and the design, construction, repair, and maintenance staff need to have a plan as well as the skills and equipment to perform repairs.

Typical Causes of Failure

System Related

Over- or under-driving the optical transmission causes intermittent or total failure.

- Too little or too much loss.
- Transmission equipment failure.
- Power failure.

Patch Panel Related

These failures could be caused by improper dressing of jumpers or cables, improper connector keying, connection contamination, improper cable routing, or localized damage. Improper bend radius, cable clamping, and improper rolls of the transmit/receive fibers are other common problems. Installations near existing fiber networks can also cause failures due to lack of attention in dressing, termination, and cable routing.

- Broken fibers at connectors and patch panels.
- Damaged cables or broken jumpers at patch panels.
- Contaminated or damaged connections.
- Miskeyed connections.
- Improper fiber rolls.
- Macrobends or microbends.

Construction or Work Related

In buildings, cuts through walls and ceilings, improper cutting of abandoned cables, and improper clamping are examples of localized failures due to poor cable identification or lack of care by workers This also could apply to backhoes and other heavy construction equipment digging cables up.

- Cable cuts in ceilings and walls.
- Cables cut from outside construction.

Human Error and Vandalism

- Automobile crashes, gunshots, etc.

Mother Nature

These failures can be catastrophic—landslides, earthquakes, floods, fires, storms, lightning, etc.—or smaller incidents such as falling branches. The best posture is to have a restoration plan current and in place to minimize the effects and severity.

Typical Cable System Faults

Fault	Cause	Equipment	Remedy
Bad connector	Dirt or damage	Inspection scope	Clean or replace
Bad pigtail	Pigtail kinked	Visible laser	Straighten kink
Damaged pigtail	Pigtail broken	Visible laser	Replace
Localized cable attenuation	Kinked cable, microbend, macrobend	OTDR	Straighten kink or remove cause of bend or stress
Distributed increase in cable attenuation	Defective cable or installation specifications exceeded	OTDR	Replace section
Lossy splice	Poor splice or improper stripping	OTDR	Resplice
Fiber break	Cable damage	OTDR/fault finder	Repair/replace
Macro- or microbend at splice	Fiber or buffer tube is stressed	OTDR/visible laser*	Remove cause of stress

*Visible lasers have limited visible range (up to 2 km).

Types of Fiber Optic Damage

Complete Cut

When the cable has been completely cut, restoring and/or rerouting the fiber span can be critical. In such cases, the problem is easy to find by most of the techniques presented in this section. Unless there is an alternate route, this situation will require immediate attention, quick identification of the location of the failure, and rapid restoration. The OTDR is used to locate the point of failure and how far in each direction the cable is damaged.

Partial Damage To Cable

This type of damage exists in the form of cuts, holes, or kinks. They can be located visually or by resistance if such damage extends to a metallic cable component. If not repaired, such areas can lead to subsequent problems with water ingress, mechanical damage, or electrical damage.

High Fiber Attenuation

The OTDR must be used to locate areas of high attenuation. They can be caused by severe macrobends in the cable (even after the cable has been straightened out) or microbends (point stresses), which are common problems in splice trays. Dual-wavelength testing (on single-mode fibers) using an OTDR with 1310 nm and 1550 nm modules is recommended for all single-mode installations. If the loss is greater at 1550 nm than at 1310 nm, the cause is either macro- or microbending.

Open Fiber

While rare, open fibers within an undamaged sheath are difficult to locate. They can evolve from installation or post-installation stresses, as well as from manufacturing defects. Finding such opens usually requires an OTDR to get a reasonably accurate distance measurement to the break. Once the sheath is opened and the fiber accessed, a fiber identifier can be used to determine the direction of the break. Most open fibers occur near splices due to improper stripping techniques, splicer settings, or splice protection placement.

Frequently Encountered Problems

Aerial

Potential causes are gunshots, lightning, fallen tree or branch, fire or severe bending. Open sheaths can allow water ingress and subsequent freezing can create fiber problems.

Ducted

Fiber and cable problems (possibly distributed) can be created by dig up, rodents, ice crushing, collapsed or crushed duct. At vault and handhole locations, cables can be improperly stressed, kinked or bent. Other possible causes of loss include improper racking, high installation (tensions) and twisting.

Underground

Problems could be caused by improper backfilling (rocks or residual bends), crushing forces, washouts, rodents, dig ups, plowing, and posthole digging. These types of problems may cause either 100% or partial failures.

Splice Closures

Problems at splice closure locations usually stem from internal fiber bend-related disorders. Look for kinked or crushed tubes, open fibers in the splice tray or overtightened tie wraps. Continuity can be checked through the splice with a fiber identifier.

Restoration Planning Questionnaire

Imagine a system failure and having to restore a damaged optical cable. Let's look at some of the issues that would need to be addressed.

1. How would the problem be identified?
2. Who is first advised of the outage?
3. Is there a technical team on call to respond?
4. Is this a dedicated route without backup or alternative routing? If yes, this requires emergency restoration.
5. If not, this could be a planned restoration. Planned restorations allow for more flexibility providing better planning and quality in the restoration.
6. Do you have records such as OTDR prints, optical power levels, and "as built" drawings on all segments?
7. Do you have an emergency restoration program?
8. Do you have emergency restoration kits?
9. Have these been evaluated with your management, engineering, construction and maintenance staff?
10. Are your circuits prioritized? Are there any contracts and/or services that could affect priorities? (e.g., emergency services, government, military?)
11. Do you have prioritized fibers?

Pair	**Signal Type**
1 and 2	SCADA
3 and 4	Protect
5 and 6	10G/Ethernet
7 and 8	Protect
9 and 10	SONET/SDH
11 and 12	Protect

12. What is the time allowance for restoration?
13. Is this a temporary restoration in which we will allow compromises on splice loss to bring the system up and will resplice later when better prepared?
14. What is the maximum allowable splice loss for restorations?
15. Are all necessary materials and equipment easily accessible by the team en-route to the outage?
    a. Restoration kits
    b. Extra splice closures and consumables
    c. Splicing tents/trucks/trailers
    d. Heaters
    e. Generators
    f. Portable lights
    g. Folding workbenches
    h. Safety equipment (barricades, flashers, warning devices), signage
    i. Fuel for generators and vehicles
    j. Spare cable
    k. Material list with suppliers' phone numbers

Restoration Planning Questionnaire

(Continued)

16. Is there a vehicle available that can allow a team to work within it so that they can work in a well lit, dry environment with a power supply?
17. How many splice and test sets do you have?
18. If using fusion splicer, do you know the specified fiber types and settings for the equipment?
19. What is the OTDR with the highest resolution? What pulse width? Wavelength?
20. Do you know the manufacturer of the fibers and the index of refraction for the cables in your system?
21. What type of communications will be used between OTDR operators and splicers?
22. What is the limitation of this equipment?
23. Will equipment such as backhoes or bucket trucks be required?
24. How do you determine the physical location of a cable cut?
25. In the case of a single cut with retrievable slack, what equipment will be used?
26. In the case of a cut without retrievable slack, what equipment will be used? Which team is quicker, Team A or Team B? Which team has the most experience?
27. In the case of massive cable failure, how many cables can you repair simultaneously?
28. Can this restoration be performed safely or will the restoration be delayed?
29. Is there anything we can do about this?
30. Where is spare cable stored and how is it identified?
31. What else can go wrong?
32. Have we missed anything?

Equipment? Environment? Staff? Tools?

Miscellaneous Issues

1. How do we keep the restoration plan and staff current?
2. Have you graded your staff on fiber optic restoration abilities?
3. Do you have annual/semi-annual procedures for testing and evaluating existing dark fibers?
4. How and where are test reports filed?
5. What about updates?
6. Each cable segment should be evaluated for worst case failures.
7. Do the emergency restoration kits include a bill of materials/check list of all tools and components and suppliers?
8. Do you have adequate amount of inventory and consumables?
9. Is any of the inventory date coded?
10. Do you photograph or film your restorations? The use of film and/or pictures provides a good learning and review tool. In the case of litigation, the pictures can be invaluable.

Pre-Emergency Planning Activities

Assemble an Emergency Response Team

The emergency response team should be made up of personnel who are aware of the implications of service interruptions in the telecommunications industry. In order to handle any emergency service interruptions you need to have a team in place before the event occurs. The team should include all those persons necessary to re-establish service in the shortest period of time. The team will need a service restoration coordinator (SRC) who will be responsible for reestablishing the service connection. Supporting the SRC will be engineers and technicians as required. The engineering effort will include input from the telecommunications sector and the outside plant sector. The technicians will include the personnel to install the new cable required to reestablish the service and make the necessary splices and checks for continuity.

Determine Standby Cable and Hardware

The first item to be addressed is how much spare material should be kept on hand. Some things to consider when planning spare cable and hardware are:

- The anticipated magnitude of damage.
- The availability of replacement materials, i.e., how long it will take to order and receive replacement cable and hardware.
- The number and location of available storage facilities.
- The acceptable amount and costs of inventory.
- The time needed to make the initial and permanent repairs.

The magnitude of the damage is critical to determining the quantities of cable necessary. If major catastrophic damage (i.e., a tornado or hurricane) that affects a large portion of an aerial system is anticipated, a substantial amount of cable should be on hand. In most instances this will not exceed 5 kilometers.

Compile System Maps and Drawings

A complete set of the system maps and drawings should be kept in a predefi ned location. Th e complete set should include the design drawings and the "as-built" drawings. If new splices are required, the restoration team needs to know how the current fi ber is routed and how the restoration is to be routed.

Designate Locations of Splices

All splice locations should be designated on the fi ber route map(s). Th ese documents should be maintained in a known area and should be reviewed periodically for changed conditions in the surrounding area. Th e splice diagram should be kept with the route maps so the personnel administering the restoration will have a clear picture of what had existed prior to the service interruption and what should be restored in order to maintain the integrity of the system.

Calculate Loss Budgets

Loss budgets should allow for the potential of added splices as a result of service interruptions and the subsequent repairs. Most loss budgets have enough margin of safety that it should not become an issue.

Develop a Call List

It will be necessary to develop a call list of all the personnel who will be needed to restore services and upper management who will be held accountable for the service interruption. In addition, develop an external call list of all entities and personnel who will be aff ected by the service interruptions.

Equipment Used in the Restoration Role

The following are listed from lowest costs to highest.

Fiber Optic Cleaning Kit

Fiber optic connectors should always be cleaned prior to mating. While it sounds basic, many faults with optical systems are caused by contaminated connectors, and are easily resolved by a simple cleaning. Remember to keep connectors clean and capped when not in use. Besides possible damage caused by contaminants, some cleaning materials can also leave residue on the fiber's endface. This residue both increases the attenuation through the connection and increases the reflectance.

Note: Analog and high-speed digital systems can be affected by the cleaning materials used.

Optical Inspection Scope

Scopes are used to identify poor connector finishes and surface contamination. Magnification can be from 100 to 400 power, with the larger magnification recommended for those working with single-mode fibers. In addition to the ability to inspect connector surfaces, newer digital scopes can store endface images for future comparison as a maintenance task.

Visual Tracers

Visual tracers are inexpensive instruments that transmit visible light through a fiber. More powerful versions use Class 2 and Class 3A red lasers operating in the visible spectrum (632-670 nm) and can locate breaks through many types of jumpers and buffered fibers. White light versions are available, but lack the power to locate internal breaks. Visual tracers are an excellent tool for troubleshooting around patch panels where the OTDR's deadzone limits its ability for short distance troubleshooting. Visual tracers can also perform quick continuity checks of FTTx drop cables.

Optical Power Meter

The optical power meter (OPM) is the essential go/no-go instrument in fiber optic troubleshooting. It should be calibrated and match the operating wavelength and connector interface of the transmission system. It allows users to check power levels (dBm) at the transmitter, receiver, or at any connection point in a system. Through good system documentation and records, the user should be able to isolate whether the problem is the electro-optical equipment or in the physical plant.

Optical Time-domain Reflectometer (OTDR)

Essential for finding faults in the outside plant, the OTDR is critical for maintenance programs and emergency restorations. It requires the most training and understanding of OTDR theory to be effective. OTDRs should be selected for both dynamic range and resolution.

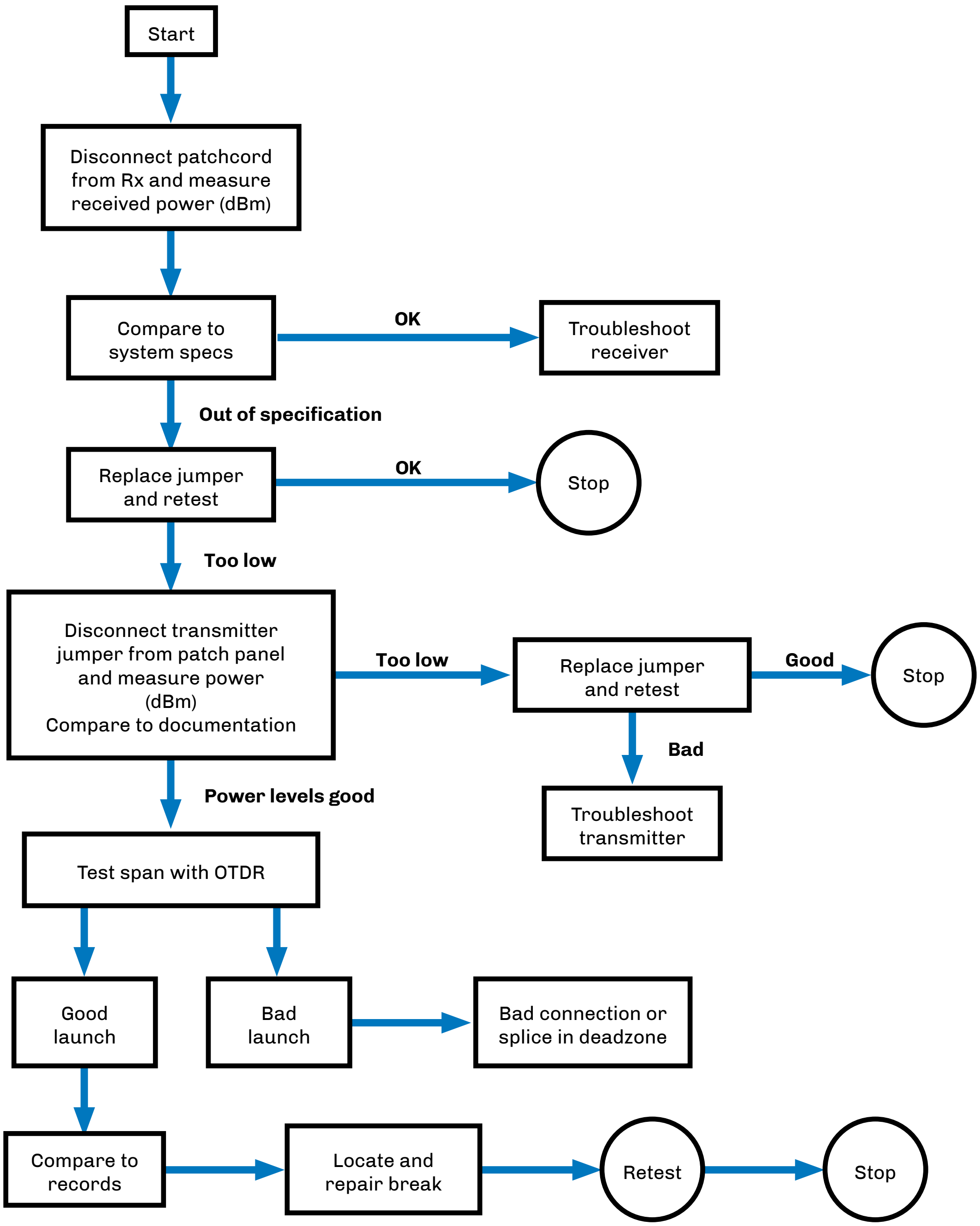
OTDR Types	Comments
a. Full feature OTDRs	Most complex and versatile – Skill required
b. Mini-OTDRs	Less expensive – User friendly
c. Fault finder	Inexpensive – Limited resolution

Troubleshooting Flow Chart

According to the flow chart below, first we intend on eliminating the transmission equipment, and then isolating the problem within the physical plant.

Once the physical fiber system has been confirmed as the point of failure, the fiber optic link must be repaired in a logical and safe process.

Cable Troubleshooting and Fault Locating



Emergency Restoration Jump Kit

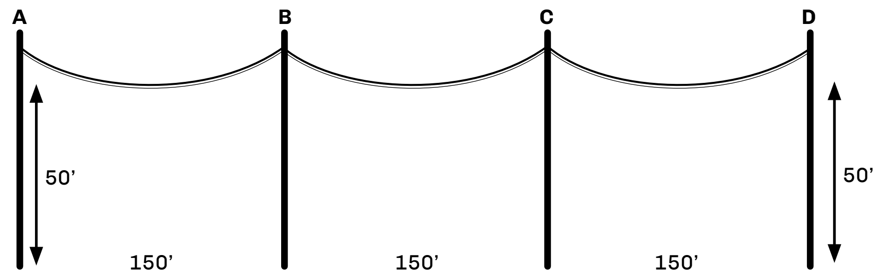
The majority of cable cuts produce only localized damage that extends 3-5 meters on each side of the cable damage area and cause a complete system outage of the primary and protect fiber transmission system. A jump kit, used for quick temporary restorations, is a short patch length method. It consists of a fiber optic restoration kit with two special organizer/closure boxes terminated on a 300' special fiber optic cable that is spooled on a quick deployment reel and packaged in a carrying case with all the necessary tools. It provides a lightweight, portable means of restoring continuity of the fiber cable without having to deploy large bulky spare cable reels and locating organizer/closure systems with their associated tools.

After the fiber system is reestablished, a permanent replacement of the damaged cable section with permanent closures and cables can be initiated with time restrictions. Once the permanent restoration is completed, the jump kit is reloaded with any consumables that were used in the restoration and relocated back with the rest of the restoration equipment.

Generic Emergency Restoration Jump Kit Requirements

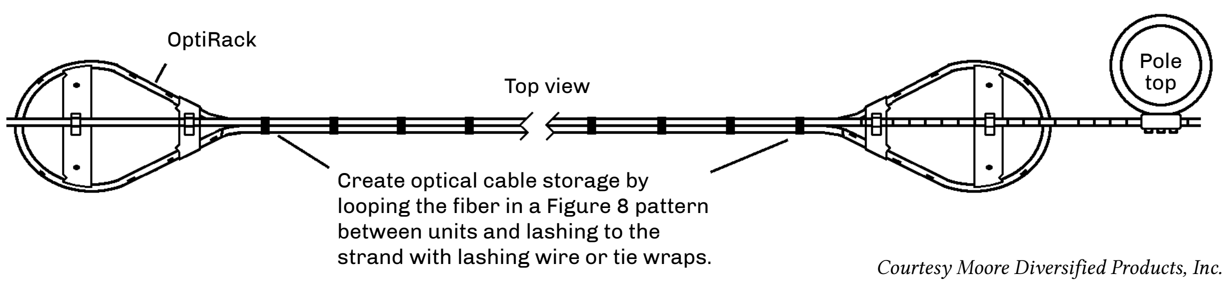
- Length of optical cable.
  - Matching fiber type.
  - Matching fiber manufacturer.
  - Must have fiber count equal to or greater than cable to be restored.
  - Cable must be longer than worst-case outage requirement.
- Closures.
  - Two needed if cut is with nonretrievable slack.
  - Splice trays to match splice protector or mechanical splice to be used in the restoration.
  - Re-entry kits.
  - Consumables.
  - Associated tools and fixtures.
  - Instructions for use.
- Splices.
  - Quantity of mechanical splices required for each splice point (plus spares).
  - Tool fixtures.
  - Consumables.
  - Instructions for use.
  - For nonretrievable slack, double the quantity.
- Tools.
  - Cleaving tools.
  - Cable preparation tools.
  - Closure tools and fixtures.
  - Instructions for use.
  - Fiber strippers.

Aerial Restoration



Scenario – Falling tree or gunshot damaged the cable on aerial span. Several repair options are listed.

Options	Cable required	Equipment required
1. **Aerial closure mounting** Retrievable slack Splice point: • Inline closure • Butt style w/snowshoes	None, with retrievable slack	Bucket truck One closure Safety issues

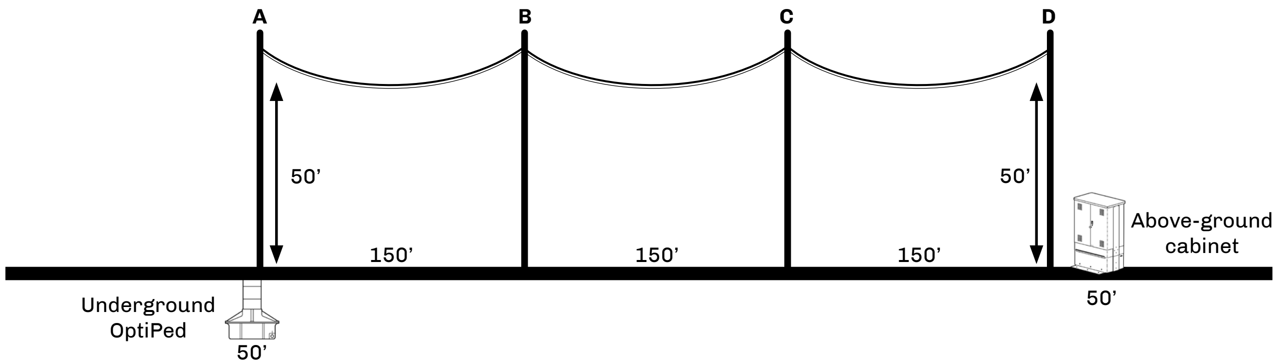


Courtesy Moore Diversified Products, Inc.

Options	Cable required	Equipment required
2. **On pole** Nonretrievable slack NEMA enclosure Size of NEMA enclosure?	550’ between A and D (450’ + 100’ slack)	NEMA closure Mounting hardware Bucket truck Spare cable Safety issues

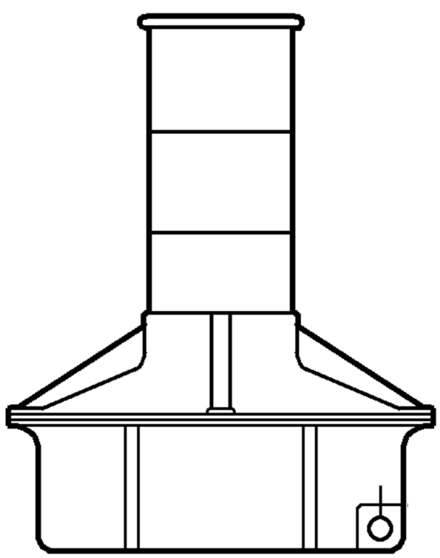
Aerial Restoration

(Continued)

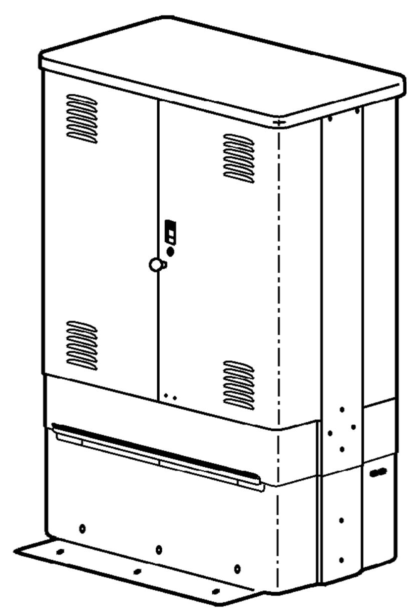


Options	Cable required	Equipment required
3. **Underground** Concrete vault OptiPed Nonretrievable slack Load bearing (?) Grounding required?	650’ between A and D (Additional 50’ per vault)	Two vaults Two closures Backhoe Cable Safety issues
4. **Above ground** Pedestals Nonretrievable slack	650’ between A and D (Additional 50’ per vault)	Two pedestals Two closures Cable
5. **Repair to closest existing splice point**	Unknown	One closure Cable Safety issues

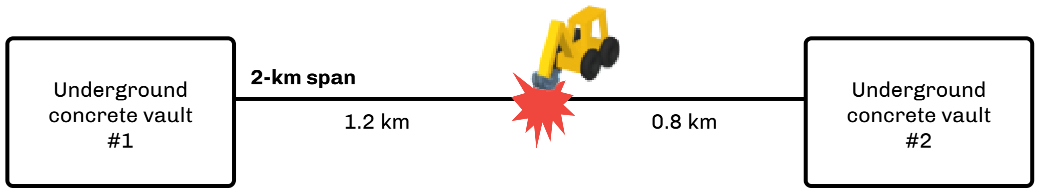
Underground OptiPed



Above-ground cabinet



OSP Restoration of Ducted Cable



Scenario: Backhoe digs up duct and optical cable, resulting in cable damage. Excess cable has been racked in vaults 1 and 2.

Option A

Repair duct and replace full span using matched cable between vaults 1 and 2, adding splice closures in each.

Sequence A

1. Remove damaged cable between vaults.
2. Prep closure(s) in vaults.
3. Deliver replacement cable and install.
4. Resplice.
5. Retest and document

Option B

Install new vault or handhole and pull cable slack back from vaults 1 and/or 2, splice, and repair.

Sequence B

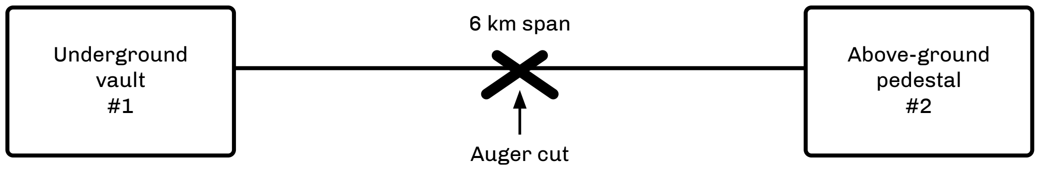
1. Install new vault or handhole.
2. Pull slack cables from vaults 1 and 2.
3. Resplice.
4. Prep splice closure.
5. Test splices with OTDR and document.

Equipment List

- Backhoe
- Splice closure(s)
- Spare cable (Option A)
- Racking hardware

- Aerial, underground, ducted, premises.
  - Preterminated drops.
    - Replace.
  - Traditional drops.
    - Identify fault location.
    - Ends: reterminate.
    - Middle: Replace span.
- Rural restorations need to be evaluated for repair versus replacement.

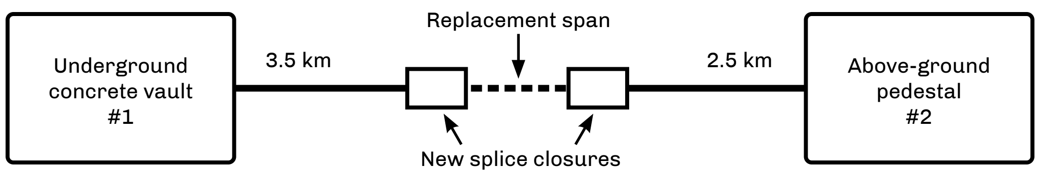
OSP Restoration of Direct Buried Cable



Scenario: Cable is cut between vault and pedestal 6 km apart (19,686 feet).

This will require a nonretrievable slack restoration replacing a span of matched fiber and cable. This will require two splice points (closures), plus vaults to protect the closures.

Remember: With nonretrievable restorations we have twice the cost, labor, equipment and attenuation versus retrievable slack.

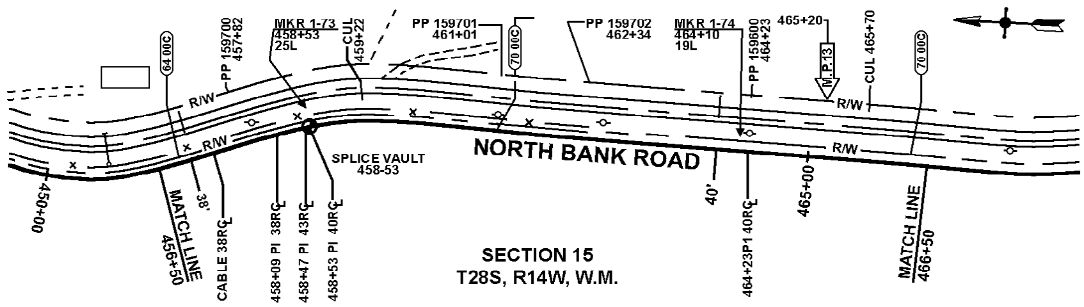


1. Identify the **<u>full extent</u>** of fiber and cable damage both visually and with OTDR.
2. Remove damaged cable.
3. Deliver emergency restoration kit (ERK) with matching optical cable.
4. Plan permanent splice vault locations.
5. Install ERK for temporary connection.
6. Place new vaults, handholes, or cabinets.
7. Prepare existing cable ends and splice closures at each end of installed cable.
8. Install new cable segment linking existing cable.
9. Cut over ERKs to a new cable and resplice.
10. Retest and document.

Equipment List

- Backhoe
- Two closures
- Two vaults, handholes and/or pedestals
- Spare cable
- Emergency restoration kit (ERK)

OSP Emergency Restoration



Scenario: Replace a 700-foot section caused by a washout.

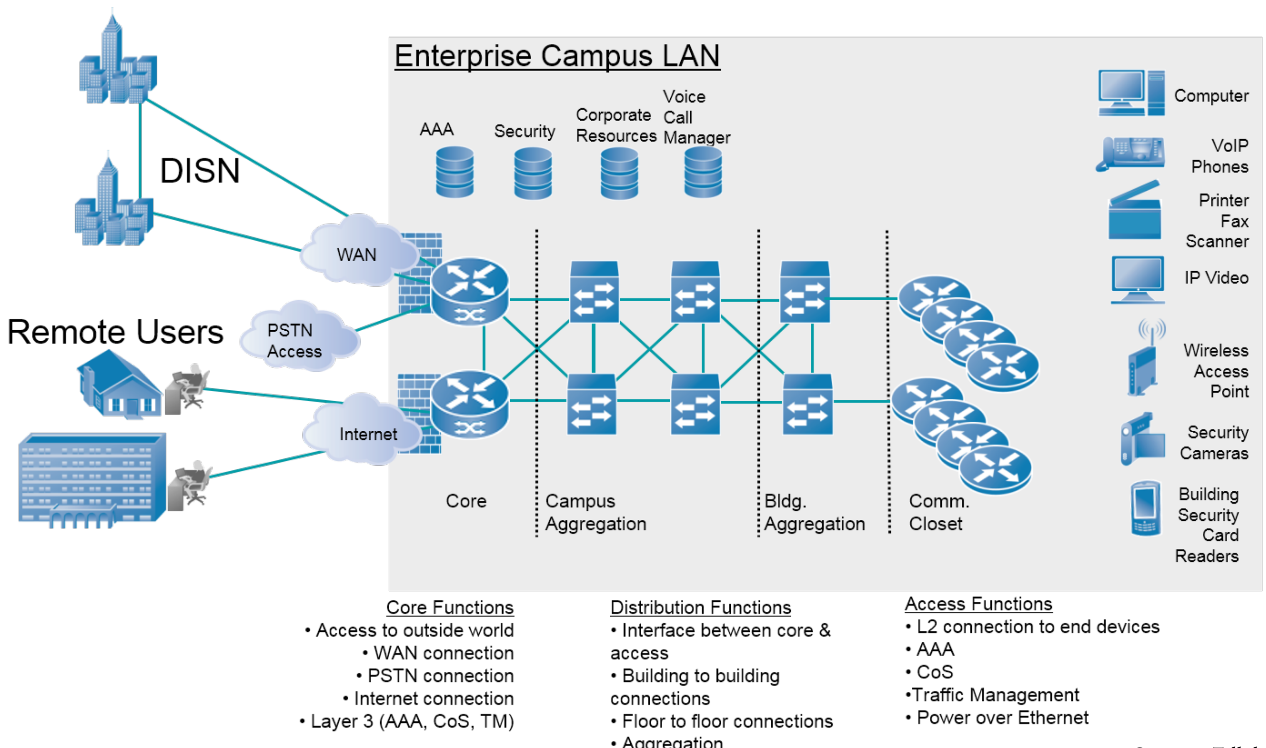
1. Establish safe access.
   a. Communications.
   b. Traffic management.
   c. Coordinate needs with repair supervisor.
2. Set up work area(s).
   a. Construction/engineering requirements.
   b. Identify permanent location.
   c. Uncover cable for preparation.
   d. Access both cable ends.
   e. Deliver restoration material (closure, equipment, cable).
3. Closure preparation.
   a. Prep cable ends.
   b. Prep closure(s).
   c. Perform temporary splices.
   d. Test for acceptable splice losses.
   e. Close and protect site.
   f. Await permanent restoration plan.
   g. Develop permanent restoration plan.
4. Schedule.
   a. Materials.
   b. Equipment.
   c. Labor (skills of personnel).
   d. Cut-over/transition.
5. Splicing.
   a. Splice priority fibers.
   b. Balance of fibers.
6. OTDR testing.
   a. Retest at 1310 and 1550 nm, bidirectionally.
   b. Documentation.
7. “As-built” drawings.
8. Replenish emergency restoration kit.
9. Post-restoration meeting.

Fiber Optic Restoration for Premises

Local area networks (LANs) consist of intra- and inter-building links over relatively short distances when compared to wide area and metropolitan area networks using optical communications. This requires different approaches and equipment to be responsive to emergency restorations.

Networks and the buildings they are in must accommodate many adds, moves, and changes over their life spans. To plan for these, designers must resolve one of the many headaches associated with LAN cable restorations: retrievable slack versus nonretrievable slack.

Will it be quicker to pull in a new cable or segment? Should a new segment be installed? Should it be spliced or connectorized? How will they be protected?



Courtesy Tellabs

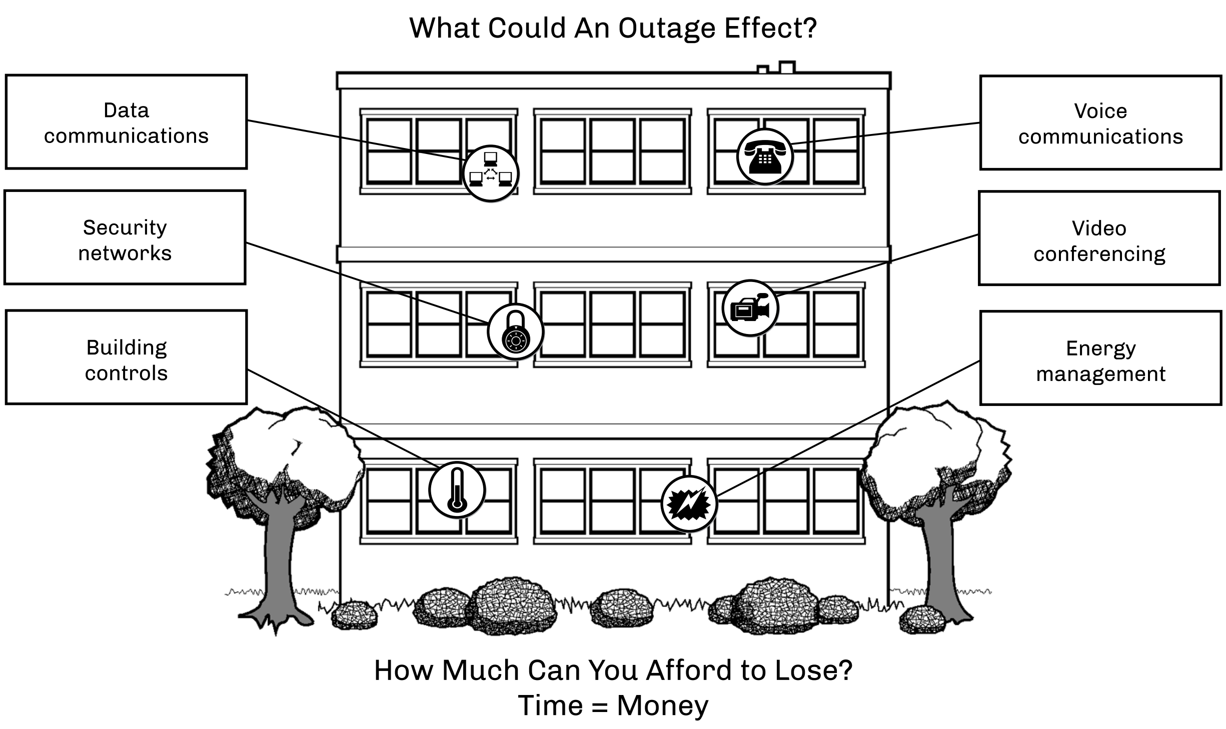
- Plan for prevention first.
  - Route diversity allows flexibility for growth, maintenance and restorations.
  - Label your cables.
  - Lock and protect locations where there is physical access to the cables and connections.
  - Only after confirming that the fault is not within the transmission equipment should you look at the physical plant.

Proactive Planning vs. Reactive Restorations

All networks start at a conceptual design stage. During this stage we must establish a value to the type of posture we should take for providing the physical plant and its protection. Today's 1, 10, and 100 Gigabit systems require planning to ensure that their entire data systems would not fail in case of either node or cable failure.

Today's designers should learn from these lessons. Most systems today use a star or point-to-point architecture and transmit at data rates of up to 10 Gb/s. Backbones for these systems require special attention to alternative routing. Networks with high data rates, critical circuits, security systems, and priority users should be designed for using route diversity. Route diversity means two specific different routes, not putting two cables in the same duct. This of course can create a cost issue in both materials and construction. If a campus is built on a system of steam tunnels in a star topology the expense would be high to create a physical ring using alternative physical routing.

Another issue to review in the design stage is the types of failures that have occurred in the past. History repeats itself, even in network failures.



Premises Restorations

Evaluating the Problem

Once the problem and location have been identified we need to restore the outage. This sounds simple but can be complex.

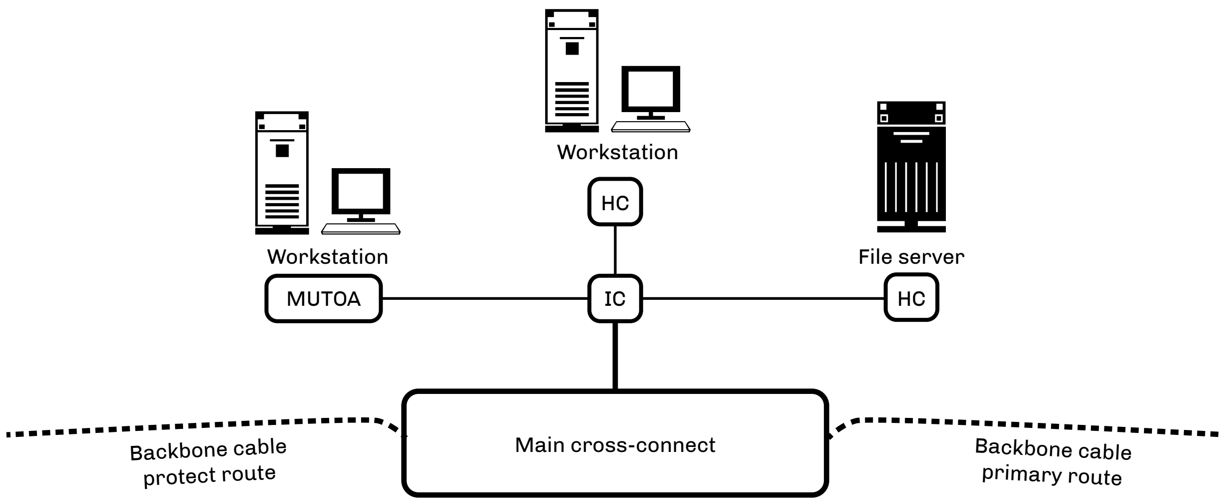
- Does the span have retrievable slack? If so, we can pull the slack back and make one repair point.
- Will it be easier and/or quicker to replace the section versus repairing the section?
- Will we terminate connectors or use quick mechanical splices for the repair? Either way we will need to protect the repair point(s). This could mean adding closure(s), patch panel(s) or rerouting of cable.
- Can the system handle the additional losses caused by the additional connectors, splices and fiber length?
- What is the worst location/scenario that can occur?
- What location on a span is the weakest link?
- If necessary, can we provide a temporary drop cable over the ceiling, in the ceiling, down the roof, etc., until a permanent restoration can be made?

The Basic Recommended Restoration Posture

All users of communications systems must have a basic posture to address what would happen should a failure occur. Following are several recommendations:

- **All** fiber routes should be properly documented including both optical performance and physical routing. This should include patch panel designations, signal type and interconnect routing information.
- All transmitters and receivers should be documented to their optical transmit and power levels. Receivers should be documented for both minimum and maximum power levels.
- All spans should be documented for optical loss. For multimode networks this would require both 850 nm and 1300 nm. Single-mode spans should be documented at 1310 nm, at a minimum. The documentation should identify the fiber manufacturer, size and type.
- If OTDR tests have been performed, copies of the OTDR traces should be included in the test reports.
- If cable has sequential markings, the difference between the markings tells us the actual cable length in meters or feet for each segment. This should be recorded in the final documentation.
- Fibers should be identified and prioritized to allow for priority fibers to be restored first.

LAN Restorations



Causes

1. Neglect/abuse.
2. Equipment failure.
3. Cable cuts.
4. Broken connectors.
5. Accidental cuts/disconnects.
6. Macrobends/microbends.
7. Poor documentation.
   a. Routing as built.
   b. Administration.
8. Vandalism.

Techniques and Options for Restoration

1. Clean connections/replace jumpers.
2. Replace cable segment.
3. Mechanical splice/repair.
   a. Retrievable slack.
   b. Nonretrievable slack (replace section).
      Replace quick connect repair.

Types of Problems

1. Cable damage.
   a. Walls.
   b. Ceilings.
   c. Floors.
   d. Ducts.
   e. Raceways.
2. Jumper related.
   a. Improper rolls.
   b. Miskeyed.
   c. Surface damage/dust.
   d. Jumper damaged.
   e. Tie wraps.

Equipment List

1. Splice closure/patch panel (1)
2. Jumpers
3. Splicing tool
4. High-resolution OTDR
5. Visual laser
6. Optical loss test set
7. No-polish connectors
8. Mechanical splices
9. Breakout kit
10. Microscope
11. Fiber optic cleaning kit

The Need for Slack Cable

Restoration planning in premise installations is like having an insurance policy. We don't benefit until we have a problem. Of course we must pay for this protection against the impacts of critical circuits being down. Should these include all voice, video and data networks, your business will soon come to a halt.

Retrievable Slack

Cable spans designed with slack points allow spare cable to be pulled together allowing for only one termination point. The use of quick mechanical splices or crimp and cleave connectors allow restoration to quickly take place.

Because most cables within the building are tight-buffered breakout or distribution style, they allow for easy re-termination. The main issue is how to store the splice/connection panel or mini closure. These products provide strain relief of the cable and physical protection of the splice or connectors.

Placement could be above the floor, wall-mounted or ceiling-mounted. In most of these situations aesthetics and size will be key factors. For many users, security and access may need to be considered.

The cable should be strain relieved and prepared leaving slack for future changes.

Emergency Restoration (With Retrievable Slack)

When the cable fault has been located, we must confirm that the cable break is where it appears to be. Spare cable can now be pulled back to the failure point, The use of visual light sources should be used to check each fiber from both ends. (We wouldn't want to have a second break point one foot away and not cut it out).

The site must be checked to find the best point and method to repair the fibers. The cable(s) may be pulled back to a ceiling, floor, post or other location for physical mounting. This location should be noted on your drawings and documented. The panel should also be labeled and possibly secured. After the cables are repaired the fiber spans should be retested for loss using the optical loss test set.

Nonretrievable Slack

Without retrievable slack we must add a section of cable to the span. This will require not only two termination points, but also twice the labor and material. We must also have a length of fiber that has equal to or greater the amount of fibers in the span. The penalty for not leaving slack is increased outage, time and cost. The processes for the reterminations are the same as the nonretrievable slack, except now we have two points that need to be repaired.

This will increase the optical attenuation of the span. Per the TIA-568 specification, 0.3 dB is allowed for each mechanical splice and 0.75 dB for each optical connection. In systems with limited attenuation margins, this may require the complete replacement of the damaged cable span.

Post-restoration Recommendations

1. Document and retest your splices, spans and segments.
2. Adjust "as-built" drawings. New vaults, closures, splices and slack cable points may need to be added or adjusted.
3. Schedule and conduct a meeting to review all aspects of the restoration.
   a. What happened?
   b. What was the cause and impacts?
   c. What did we do well?
   d. What didn't work? Technique, equipment, products, staff.
   e. How can this be resolved?
   f. How can we improve?
   g. What needs to be done to rebuild kits and replenish inventory?

Chapter 12 Review

1. What are the three main keys to a fast and efficient restoration plan?

2. What is the objective of a restoration plan versus a maintenance posture?

3. What types of equipment are ideal for a restoration posture?

4. True or false: Consumables such as pre-built splice kits, proper cleaning materials, splice sleeves, connectors, drop cables, and cable gels should be kept on hand for a restoration.

5. What is the impact of a nonretrievable versus a retrievable slack scenario?

6. What are as-built drawings?

7. For OSP restorations, what types of equipment would be required?

8. Upon completion of the restoration, what is the purpose of a post project meeting?

9. Will the OTDR show the actual break and damage location of a cable cut?

10. In premises restorations, what technique would be best for immediate repairs? What are the options?

Student Notes

Chapter 13

Communication System Basics

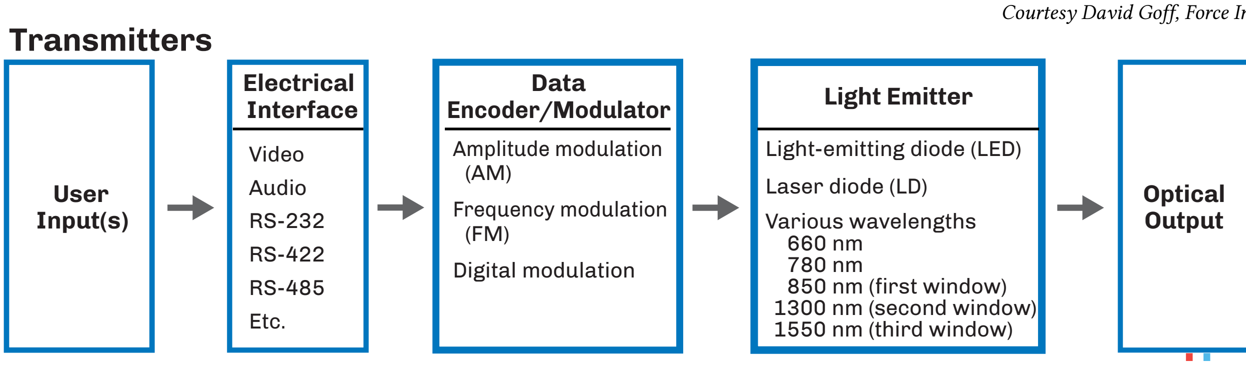
By the end of this chapter, you will be able to:

- List types of active devices and give a basic description of their function
- List types of passive devices and give a basic description of their function
- Name the three primary methods of multiplexing

Fiber Optic Transmitters

The optical transmitter uses an electrical interface (voice, video, data) to encode the information through modulation techniques. Most common are frequency modulation (FM), amplitude modulation (AM), and digital modulation..

Courtesy David Goff, Force Inc.



Electro-optic components provide the physical interface between the electrical systems and the optical fiber. An LED or laser converts electrical pulses into optical pulses. At the other end of the link, a PIN or APD photodiode converts the optical pulses back into current pulses. The wavelength of the source light must be compatible with the detector and fiber.

The drive and receiver circuits shape, time, and amplify electrical pulses to provide proper signal waveforms. They also provide bias to the electro-optic devices. Since these devices are diodes, the electrical design is similar to the design of other high-speed systems.

- Electro-optic components provide the physical interface between the electrical systems and the optical fiber.
- The electrical drive and receiver circuits shape and amplify the signal wave form.

Laser Light Sources

Light **A**mplification by **S**timulated **E**mission of **R**adiation

Laser diodes are solid-state semiconductor devices that produce light and transmit analog and digital signals. By directly modulating the electrical signal, the laser transmits the signal by an optical format. Stimulated emission is the process that lasers used to generate light energy where each photon has the same wavelength, phase relationship, and direction as the first photon. High-speed lasers may use external modulators and are coupled with optical isolators for reduction of reflections.

The two dominant types of lasers used in single-mode systems operating at 1310 and 1550 nm are the Fabry-Perot (FP) and the distributed feedback (DFB) semiconductor lasers. For multimode systems, the vertical-cavity surface-emitting laser (VCSEL) was developed in the 1990s for Gigabit LANs and SANs (up to 10 Gb/s) operating at 850 nm over laser-optimized multimode fibers.

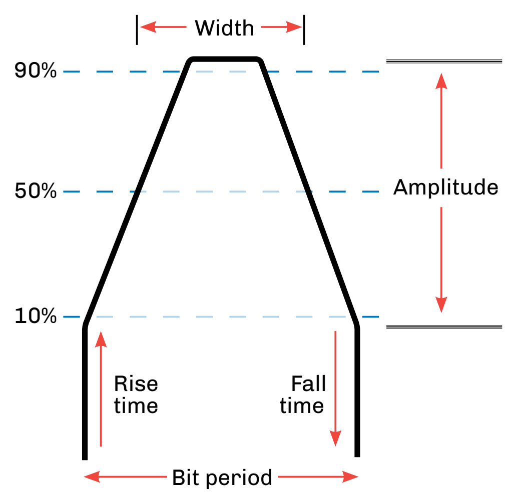
Parts of the Pulse

Amplitude – The height of the pulse defines the energy or optical power.

Rise and fall time – The time required for a pulse to rise from 10% to 90% (rise time) of its amplitude and the reverse occurring for the fall time.

Pulse width – The width of the pulse expressed in time at 50% of the amplitude of the pulse. With light sources it is usually expressed as full width at half maximum (FWHM) power.

Bit period – The time given for a pulse. Most digital timing is essential for high-speed systems to keep the information in synchronization.



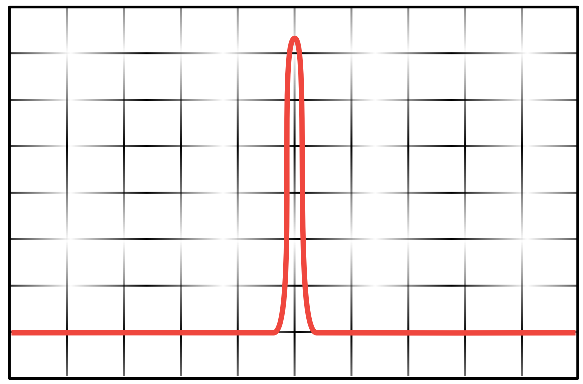
- The Fabry-Perot (FP) and distributed feedback (DFB) lasers are used in single-mode transmitters.
- The vertical-cavity surface-emitting laser is used in multimode transmitters.
- Solid-state semiconductor devices that produce light and transmit analog and digital signals.
- Amplitude of the pulse is peak power.
- The spectral width of the pulse affects optical dispersion.

Lasers in Single-mode Systems

Distributed Feedback Lasers

Used in digital, DWDM, long haul, and high-speed systems, the distributed feedback (DFB) laser is a semiconductor diode used in optical transmission systems that require high performance optical transmitters. Cooled DFB lasers emit very narrow stable wavelengths that are suitable for dense wavelength division multiplexing (DWDM) transmitters. The narrow spectral widths displayed by DFB lasers can also benefit high-speed data links by limiting the effects of chromatic dispersion.

- Used in analog and digital systems.
- Higher priced than FP lasers.
- Data rates greater than 10 Gb/s.
- Narrow spectral width is ideal for DWDM.
- Applications.
    - DWDM systems.
    - Oceanic systems.
    - Long haul.
    - CATV (analog) systems.
    - High speed digital systems.
    - Optical line terminals in FTTx systems.

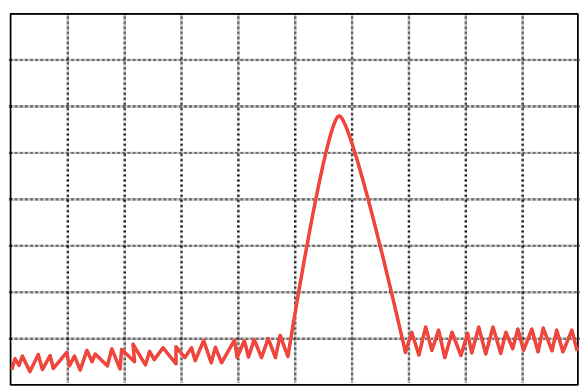


Narrow DFB spectral width
Less than 1 nm

Fabry-Perot Lasers

Used in digital single-mode systems at data rates lower than 10 Gb/s, and in multimode systems operating at 1300 nm, Fabry-Perot (FP) lasers were the first solid-state semiconductor laser diodes, and are often referred to as multilongitudinal mode (MLM) lasers. Compared to DFB lasers, they are more economical to manufacture, but tend to be noisier and slower.

- Used in digital single-mode systems.
- Data rates lower than 10 Gb/s.
- Economical to manufacture.
- Noisier and slower.
- Spectral width typically 4 nm or greater.



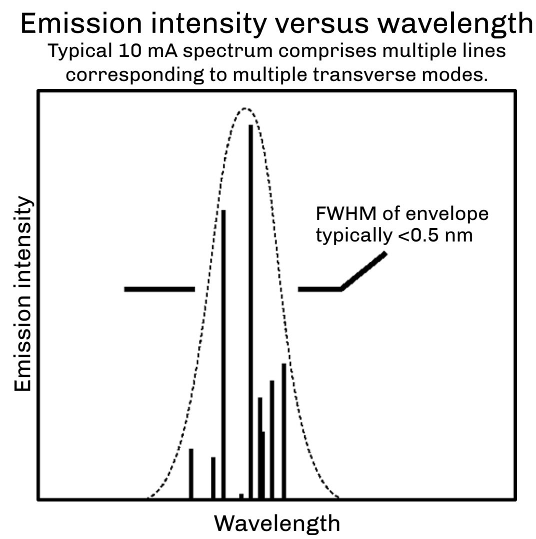
Wide FP spectral width
Typically 4 nm or greater

Light Sources in Multimode Systems

Vertical Cavity Surface-emitting Lasers

Lasers and LEDs have worked as the light sources for optical networks for many years. When fiber optic Gigabit Ethernet products were developed, LEDs could not be modulated at the required speeds, and Fabry-Perot lasers were too expensive. The solution came with the vertical cavity surface-emitting laser (VCSEL). It provided a low-cost solution at 850 nm and could be modulated at Gigahertz levels. This required multimode fibers to be modified in order to transmit laser signals. These are specified by the IEC as laser-optimized OM3 and OM4 50/125 multimode fibers.

- OM3 and OM4 multimode fibers are designed for use with VCSELs at 850 nm.
- Small beam divergence provides easy coupling to multimode fibers.
- Available for 850, 1310 and 1550 nm operation.
- Standard T0-46 or surface mount packaging.
- Data rates up to 10 Gb/s.
- Meets IEEE-802.3z (Gigabit Ethernet), ATM, Fibre Channel, and HIPPI requirements.
- Low power consumption.
- Class I and III safety levels.
- Connector packages for simplex, duplex and ribbon configurations.
- Compatible with low-cost PIN detectors.

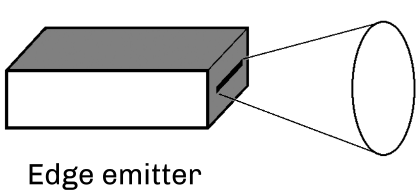


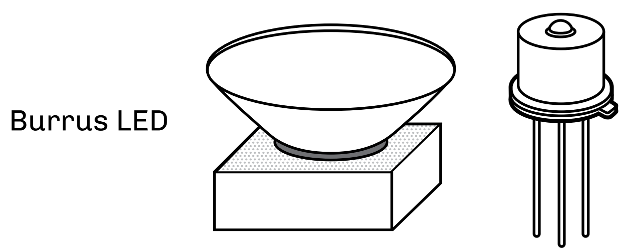
Light-emitting Diodes

Light-emitting diodes (LEDs) are inexpensive solid-state devices that convert an electron flow into photons. They can be directly modulated up to 622 MHz. For short-distance and low-speed multimode systems operating at 850 nm or 1300 nm, the LED has good coupling efficiency when used with the larger cores of multimode fibers. The main limitations of the LED are its wide spectral width and limited modulation speeds. It has provided the solution for the increasing speed requirements of local and storage area networks.

There are two main types of LEDs:

1. The surface-emitting LED is reliable, less expensive, and has a very wide (180°) emission pattern, limiting range and bandwidth. These are typically found in low power and low bandwidth devices. Two common types are the Burrus and well.
2. The edge-emitting LED is designed to have the optical output exit from the side of the emitter. They are typically found in high power and higher bandwidth multimode applications.





Laser and LED Spectral Width

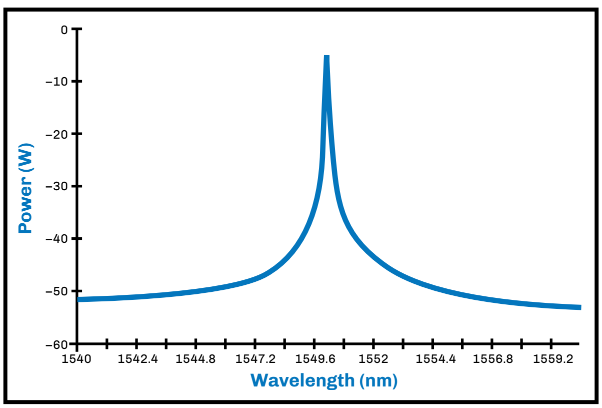
Lasers and LEDs emit light over an area greater than the specified wavelength. This spectral width (or line width) creates signal dispersion, which limits bandwidth. Narrower spectral width allows for higher data transmission rates over longer distances. The power from lasers is many times higher than that of LEDs in this narrow range of wavelength; it wouldn't even fit in the same power scale.

The chromatic dispersion of a fiber increases with the source spectral width. The laser, with its narrow spectral width, provides reduced chromatic dispersion.

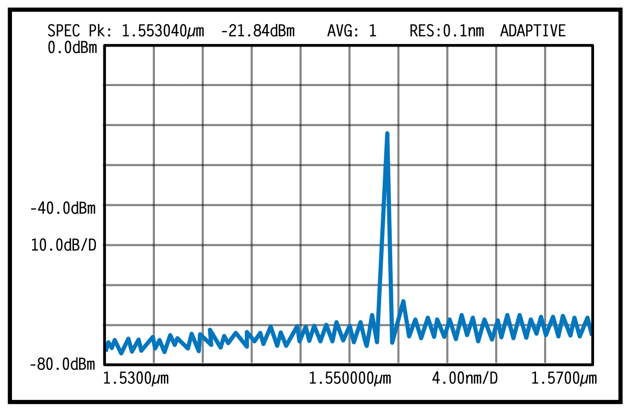
Full Width Half Maximum (FWHM)

Full width half maximum is a measurement of the spectral width of a light source. Measure the spectral width at −3 dB (half power from peak) and at the full width of the source's power peak.

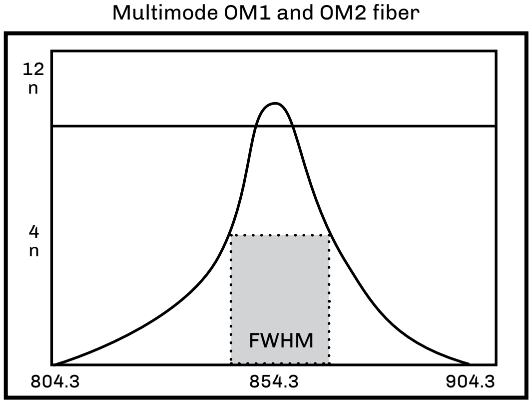
Distributed feedback laser
Single-mode
Measurement of long-wavelength laser diode



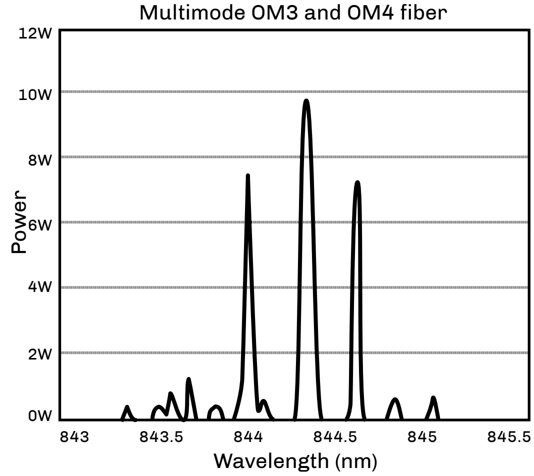
Fabry-Perot laser
Single-mode, and multimode at 1300 nm
Measurement of wavelength and level differences



LED (FWHM)
Multimode OM1 and OM2 fiber



VCSELs
Multimode OM3 and OM4 fiber



Reflection Issues

The reduction or elimination of reflections is an issue all system designers must consider in designing a fiber optic link. Active components such as lasers, and in some cases even the receivers themselves, are affected by reflected energy.

All high-speed fiber transmission systems use laser diodes for optical transmission. Distributed feedback or Fabry-Perot lasers are sensitive to optical signals that are reflected by optical components back into the lasing cavities. The closer the reflective component is to the laser and the higher the reflection itself, the greater the impact of the reflection will be. VCSEL lasers are reflection-insensitive, and LEDs are not affected by reflections.

This reflective energy can modulate the laser's power output and/or the laser's spectral frequency. The change in the modulation of the laser power directly causes an increase in the system's bit error rate (BER). This change can also impact adjacent wavelengths in DWDM systems and increase the chromatic dispersion, impacting the BER.

The major cause of reflective energy is Fresnel reflection, caused by abrupt changes in the refractive indices caused by glass-to-glass surfaces, glass-to-air surfaces and glass-to-other surfaces. These are commonly caused by connectors, mechanical splices, lensed devices and unterminated optical splitters.

Manufacturers and users typically specify optical return loss (ORL) levels required for the optimum level of the equipment manufactured or installed. Special polishes have evolved over the years including UPC (ultra physical contact) and APC (angled physical contact) to reduce Fresnel reflections.

	Analog	**Digital**
Light sources	LEDs (unaffected) DFB lasers	LEDs and lasers (VCSEL, Fabry-Perot and DFB)
Detectors	PIN-type detectors only	PIN and APD types
Connectors	Low-reflection polishes required (PC, UPC, APC)	All types (PC types recommended)
Splices	Fusion (nonreflective)	Mechanical or fusion

- LEDs are not affected by reflected energy.
- Lasers are effected by ORL and component reflectance.
- High speed digital systems >1 Gb/s can be effected by ORL.
- All analog systems using lasers are affected by reflections.
- Designers and installers should pay close attention to reflective components (especially connectors).

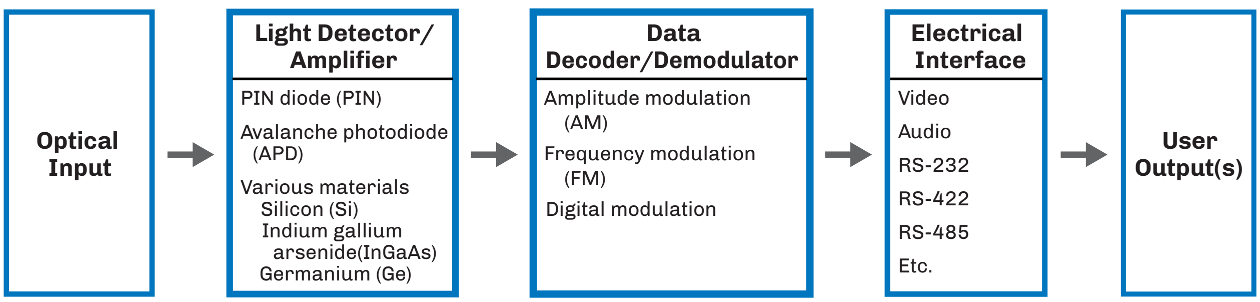
Fiber Optic Receivers

Optical detectors, also known as photodiodes and photodetectors, perform the reverse function of the light source – they convert incoming optical signals (light energy) into electrical signals (energy) that can be processed with conventional circuitry within the optical receiver.

The receiver converts and decodes the optical signal back into electrical signals through the use of either PIN or APD photodetectors. This received and amplified signal is then sent to a data decoder or demodulator that converts the electrical signal into the user protocol and format (voice, video, and data).

There are three parameters used to characterize a photodiode: responsivity, sensitivity, and speed. The responsivity is the output current divided by the input power and has units of amp/watt. The sensitivity is the minimum signal, which can be detected in the presence of noise from the photodiode and preamp. The speed is how quickly the photodiode can modulate light.

Receivers



- Photo diodes (detectors) convert optical pulses back into electrical pulses.
  - PIN.
  - APD.
- Three parameters characterize a photodiode:
  - Responsivity – Output current divided by the input power.
  - Sensitivity – The minimum signal that can be detected in the presence of noise.
  - Speed – How quickly the photodiode can demodulate optical signals.

Detector Requirements

- Faster modulation than the source.
- High output current (high responsivity).
- High gain and sensitivity (APD).
- Low noise (both photodetector and preamp).
- Low bias circuit complexity (PIN).
- Wavelength compatible with source and fiber.
- Large size (compared to fiber core diameter).

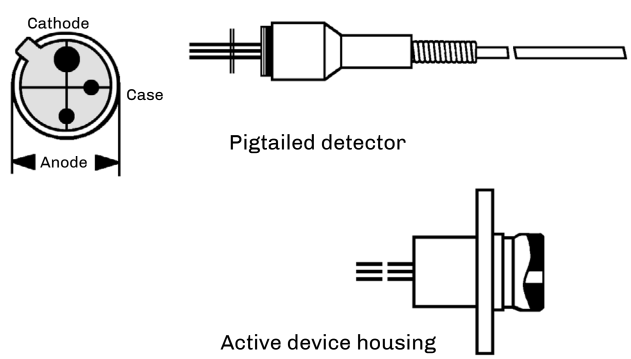
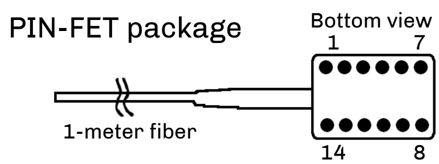
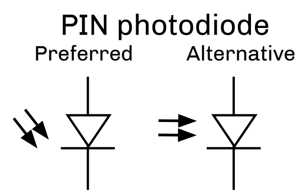


Photo Diodes

PIN Diodes

The photo diode (or photo detector) is an active device that receives and converts optical pulses into electrical pulses. The optical signal at the end of the link has usually been attenuated and is of low power, resulting in a correspondingly low output current. Therefore, a photo diode is normally packaged with a sensitive preamp to improve performance. The more common type of diode used, positive–intrinsic-negative (PIN) diodes are relatively inexpensive and do not require great amounts of power, but are limited in sensitivity. They are most often used in short (<30 km) spans.





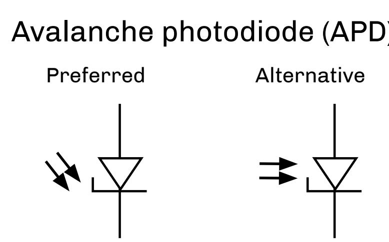
- Used in both digital or analog systems.
    - The only detector type than can be used in analog systems.
- Limited sensitivity.
- Low power input.
- Performance is based on a number of key operating parameters, such as dynamic range, sensitivity, and frequency response.

Avalanche Photodiodes

Avalanche photodiodes (APDs) are photodiodes that produce gain, e.g., amplification, and they are generally used with excessively lossy or long-distance systems. The drawback is the higher circuit complexity and cost. APDs use internal current gain to amplify the photocurrent by approximately 10 to 50 times. The APD gain is very sensitive to the amount of reverse bias voltage and ambient temperature. Properly biased, APDs provide 4-10 dB of gain (adjusted for temperature variations). At a typical single-mode fiber loss of 0.25 dB/km, this corresponds to an additional 16-40 km of fiber.

Telecommunication systems utilize sophisticated temperature and gain-stabilizing circuitry to ensure that the sensitivity of the receiver remains constant. In order to reduce costs, optical receivers with APDs in standard ITS systems typically use the APD with only a small amount of temperature or bias voltage adjustments. Since the optical receivers are typically located in environmentally-controlled facilities, the temperature variation and thus the APD gain will be relatively constant and not adversely affect the performance of the transmission system.

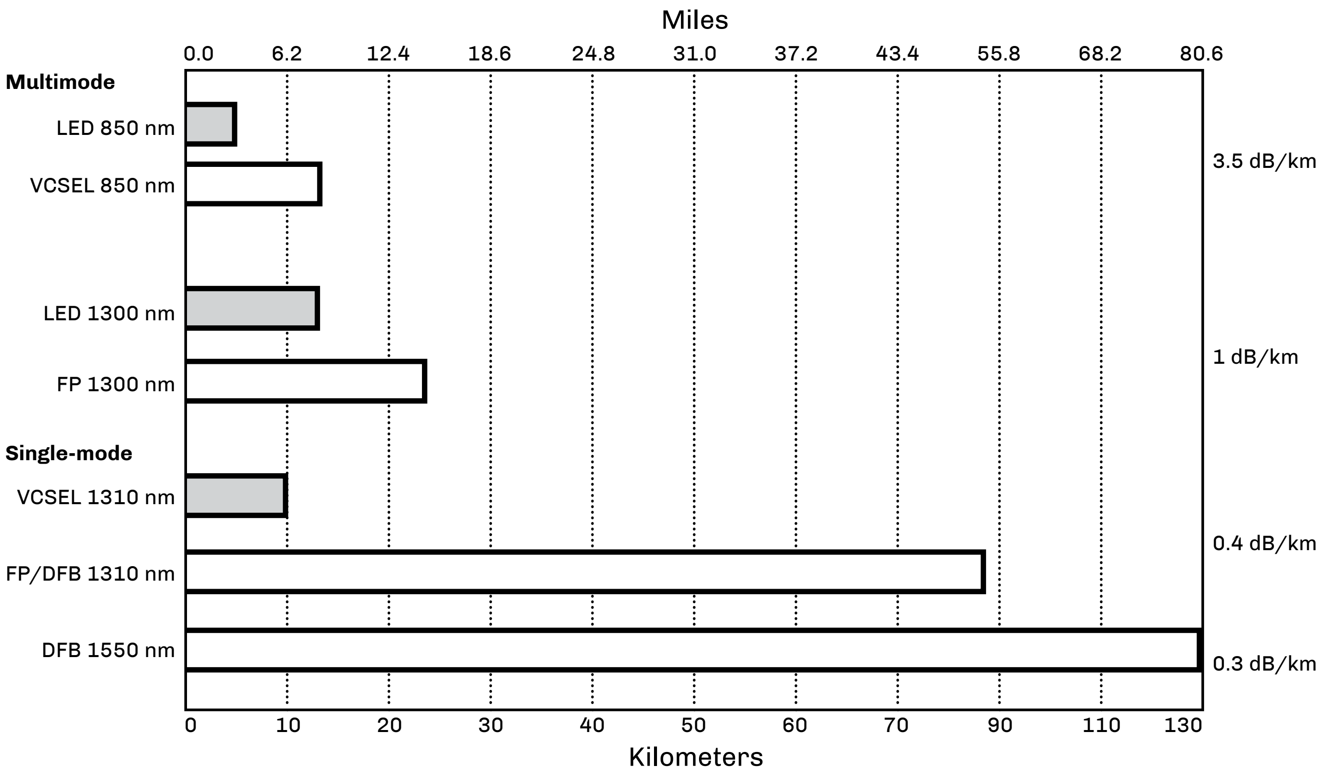
- Produce gain (10 dB).
- Amplify photocurrent by 10 to 50 times.
- Used in digital receivers.
- Used with excessively lossy (FTTH) or long-distance systems.
- Cannot be used in analog systems.
- Higher circuit complexity and cost than PIN types.



Typical Span Distances

Based on Optical Power Levels

Span distances are based on typical optical loss budgets using LEDs, lasers, and PIN/APD photodetectors over different fiber types and at different wavelengths. A bandwidth calculation for multimode fibers or dispersion calculation for single-mode fibers should be performed to verify link is within acceptable limits.

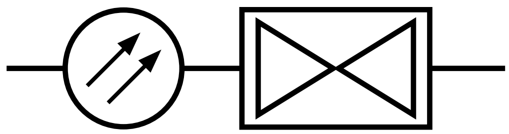


LED	Light-emitting diode
VCSEL	Vertical-cavity surface-emitting laser
FP	Fabry-Perot laser
DFB	Distributed feedback laser

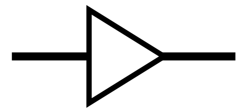
Typical Optical Detector Specifications

	Silicon (Si)		Germanium (Ge)		Indium Gallium Arsenide Phosphide (InGaAsP)	
	PIN	APD	PIN	APD	PIN	APD
Wavelength (nm)	400-900	400-900	500-1800	700-1550	900-1700	900-1700
Photon to electron conversion gain	1	150	1	10-50	1	150
Sensitivity (dBm)	–30	–40	–30	–40	–30	–40

Repeaters, Regenerators, and Amplifiers



Bidirectional



Unidirectional

Repeaters and regenerators are used where the fiber-optic span distance is greater than the allowable link attenuation margin, or where the signal dispersion is such that it affects the bit error rate (BER) for digital systems and carrier-to-noise ratio (CNR) for analog systems. They compensate for high attenuation levels, excessive fiber (span) length, splitter attenuation, or increased signal aging losses. The words "repeater" and "regenerator" are sometimes used interchangeably.

Optical electrical regenerators – The most common type used in telecommunications systems, the O/E–E/O regenerator performs "3R" retiming, reshaping, and reamplification, and also may have add/drop capabilities. The unit receives the optical signal, converts it to an *electronic* signal, which is retimed and reshapes before it is converted to an optical signal. Once in the electrical domain, retransmission allows the wavelengths and fiber types to be changed, if needed.

The Three "R" Functions

Retime	Electrical
Reshape	Electrical and/or optical
Reamplify	Electrical and optical

Regenerator – A digital term for a receiver and transmitter combination used to reconstruct signals for digital transmission. In an optical regenerator, the receiver converts incoming optical pulses to electrical pulses, decides whether the pulses are 1s or 0s, generates clean electrical pulses and then converts them to squared off pulses for transmission.

Repeater – An analog term for an opto-electronic device inserted at intervals along a circuit to boost and amplify an analog signal being transmitted. Repeaters also regenerate digital signal, squaring it and cleaning it but not changing it. Regenerating the signal removes noises and thus reduces the likelihood of errors. Also called regenerator repeater.

Fiber optic amplifier – Optical amplifiers are only applicable to single-mode systems. There are three types available. All require power to operate and may not be appropriate in applications where access to power is limited.

- Erbium-doped fiber amplifiers (EDFAs).
  - Common in terrestrial telecom market, EDFAs use a special erbium fiber and an optical pump laser to provide gain of the incoming signal without conversion to an electrical signal.
- Raman amplifiers.
  - Raman amplifiers are more complex and use the transmission fiber itself to provide gain. This type is mostly used in long-distance submarine and long-haul systems.
- Semiconductor optical amplifiers (SOAs).
  - SOAs are small, low-cost devices that are used in many terrestrial applications with only a small gain (6-10 dB) is required. SOAs are a good choice in applications that require gain and in-line amplification.

Factors for Regenerator Usage

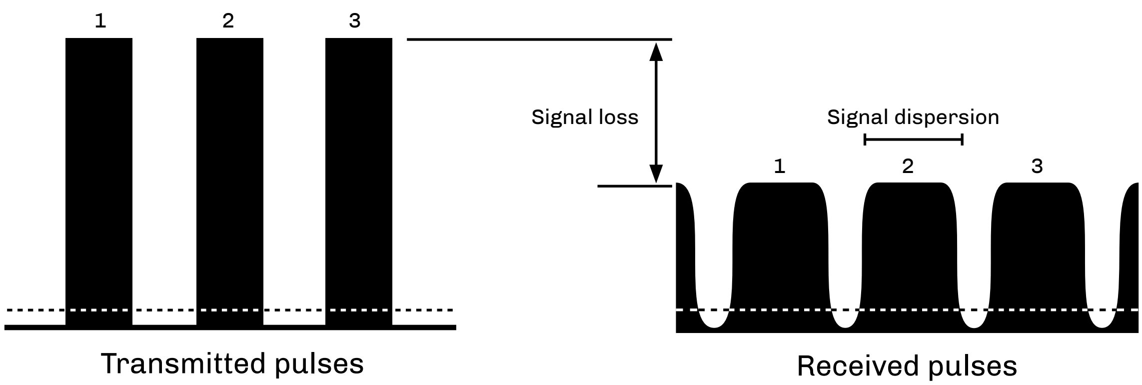
Attenuation

Attenuation occurs where the loss is greater than the link loss budget allows. The signal loss is the combined attenuation of the fiber, splices, connectors, and jumpers in the system. This amount may increase over time due to splices, added components, aging, or stress placed on the optical cable or components.

Signal Dispersion

Signal dispersion occurs when the signal spreads to the point that pulses overlap and cause the receiver to detect one long pulse instead of three shorter pulses. At faster data rates, this effect is more pronounced.

An example of a chromatic dispersion problem could occur when the data rate is increased from 2.5 Gb/s to 10 Gb/s. This would result in a 16 times increase in signal dispersion. Resolutions include narrower spectral width lasers, dispersion and/or compensating fibers or modules.



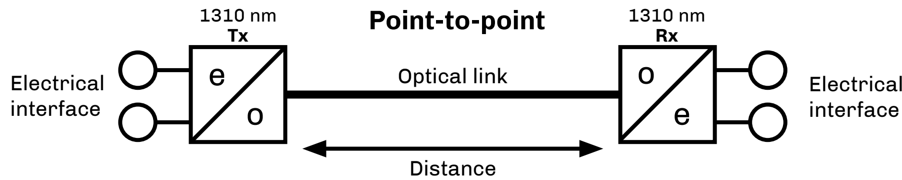
An example of modal dispersion can occur when a legacy 62.5/125 multimode fiber was installed for use in a fast Ethernet (100 Mb/s) application over 1 km (3,281 feet). Upgrading to Gigabit Ethernet (GbE), the attenuation hasn't changed, but the data rate and modulation required has increased tenfold. The modal dispersion, also known as differential mode delay (DMD), now limits the span distance to a best case of 550 meters.

Types of Optical Dispersion

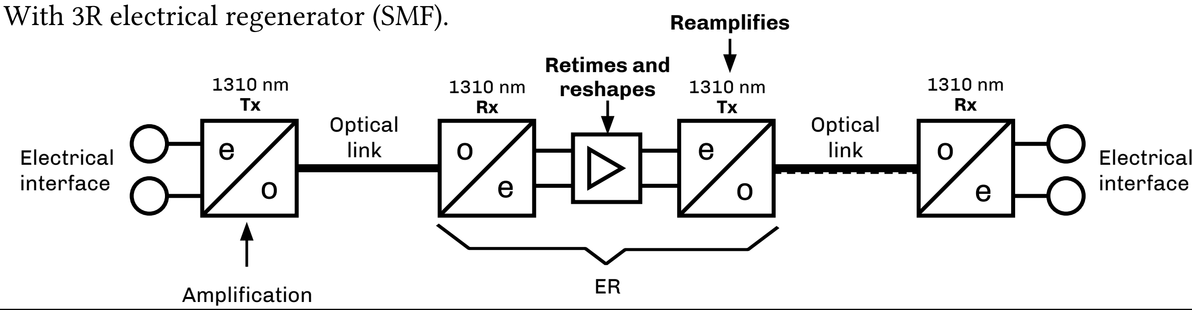
Single-mode	• Chromatic dispersion (CD).
	• Material dispersion.
	• Waveguide dispersion.
	• Polarization mode dispersion (PMD).
Multimode	• Modal dispersion or differential mode delay (DMD).

Basic Components for Optical Transmission

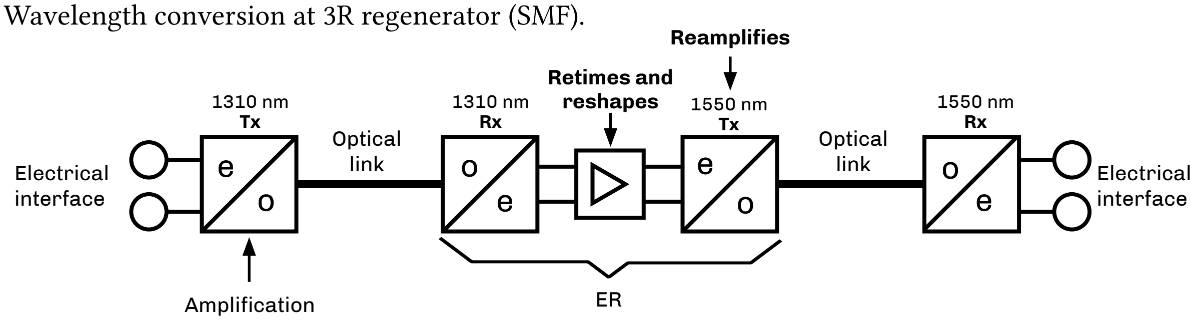
1. Without regenerator (SMF).



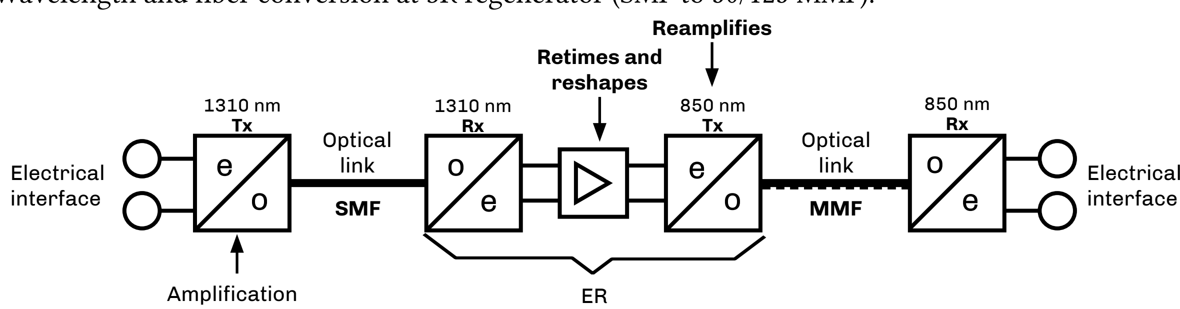
2. With 3R electrical regenerator (SMF).



3. Wavelength conversion at 3R regenerator (SMF).



4. Wavelength and fiber conversion at 3R regenerator (SMF to 50/125 MMF).



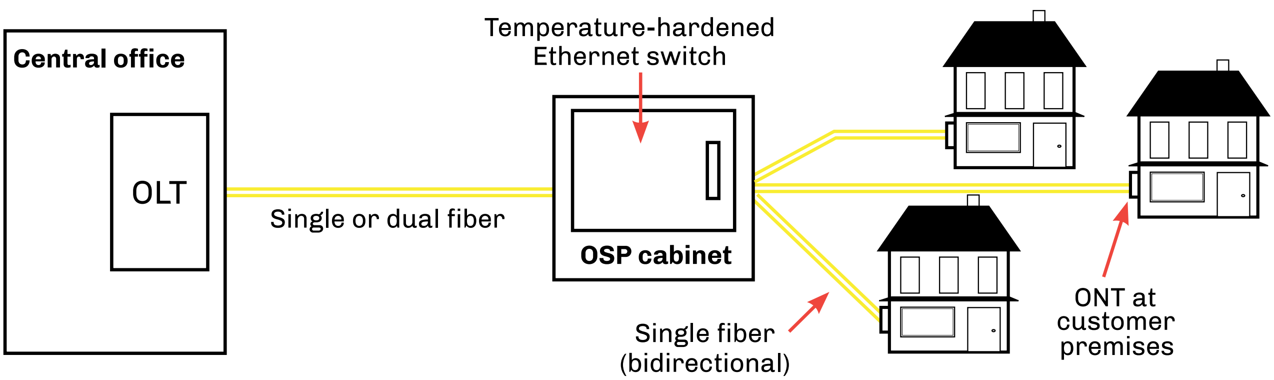
KEY	
Rx	Receiver
Tx	Transmitter
e/o	Electrical to optical, e.g., laser transmitter
o/e	Optical to electrical, e.g., photodetector/receiver
ER	Electrical regenerator (repeater)
3R	Retime, reshape, reamplify

Point to Point

FTTx Active Ethernet Example

All point-to-point (P2P) optical transmission system consists of three parts: the transmitter, the receiver, and the physical plant. Most transmitters and receivers use SFP and SFP+ modules at transmission locations. From the hub site to a powered cabinet, it has greater distance capabilities than point-to-multipoint (P2MP), as it does not use lossy optical splitters. The P2P option uses optical switches and can be adapted to handle various types of voice, video, and data services at multiple data rates. Most FTTx P2P systems use Ethernet, as it handles the transmission of Internet protocol (IP) data and can provide voice (VoIP), video (IPTV), and data communications.

To consider the maximum distance for a P2P system, designers first must consider if an existing standard covers the application for the specific protocol and data rate. Other considerations are the optical attenuation level for the selected transmission wavelengths, the optical dispersion over the fiber type to be installed, and the type and spectral width of the system's laser.



FTTx Residential Installation Comparison

	Active Ethernet (P2P)	PON (P2MP)
Architecture	Dedicated	Shared, up to 1:64
Range	Up to 80 km	Up to 20 km
Data rates	Up to 10 Gb/s	Up to 10 Gb/s shared
Transmission fibers	Two fibers (LX) Single fiber bidirectional (BX)	Single fiber bidirectional (BX)
Fiber requirement	Fiber rich	Fiber lean
Costs to deploy	Higher (requires more fiber)	Lower (more fiber efficient)

- Dedicated architecture between transmission equipment.
- Easy to test and troubleshoot.
- Ring and star topologies consist of multiple P2P segments.

Point to Multipoint

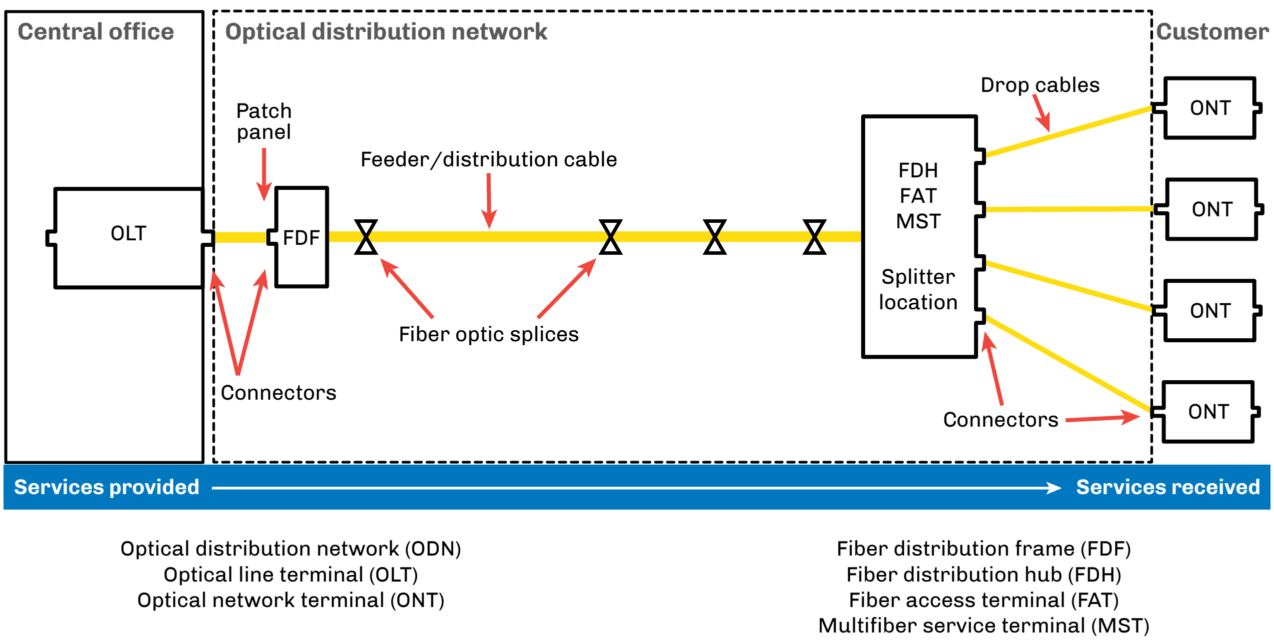
FTTH PON Example

Passive optical networks (PONs) use the star or point-to-multipoint (P2MP) topology and optical splitters, which eliminate the need to power any part of the outside plant. Optical splitters allow a minimal amount of fibers to reach a maximum number of end users. Most PON systems can link 32 optical network terminals (ONTs) located at subscriber locations to one optical line terminal (OLT) line card located at the service provider's hub. The Gigabit PON (G-PON) standard allows up to 1:64 configurations.

The major cause of attenuation will be the optical splitters. Standards have identified and specified optical distribution network (ODN) classes for various power levels. Unlike long P2P spans, optical dispersion will not be a major problem.

Since the physical fiber span in the PON is protocol independent, ATM (cell-based) and Ethernet (packet-based) standards handle triple play (voice, video and data) services. RF overlay uses an external wavelength division multiplexer (WDM).

Another variation of the PON based P2MP topology are WDM-PON systems for next generation (NG-PON) networks. The use of passive WDM products can allow for each customer to have a dedicated wavelength providing the most bandwidth available for future migrations.

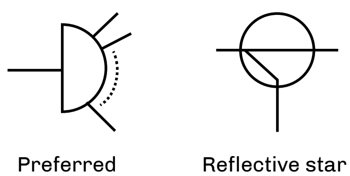


Typical point-to-multipoint passive optical network

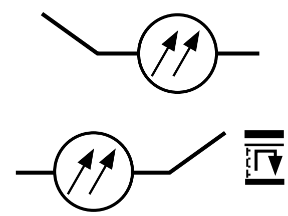
Passive Devices

Fiber optic passive devices are components that do not require electrical-to-optical or optical-to-electrical conversion during its operation. They give designers the ability to direct, split, control, multiplex, demultiplex, and switch optical signals. They also provide flexibility in operating, monitoring, testing and maintaining optical networks. Fiber optic passive devices are specified by the ITU-T G.671 "Optical Components and Subsystems" standard. Types of passive devices include:

- Optical splitters (also known as optical couplers).
- Wavelength division multiplexers (WDMs).
- Filters.
- Isolators.
- Optical switches.
- Attenuators.
- Optical dispersion compensators.

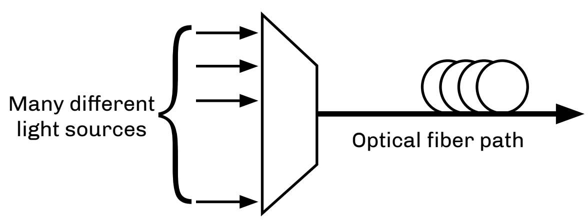


Optical splitter examples

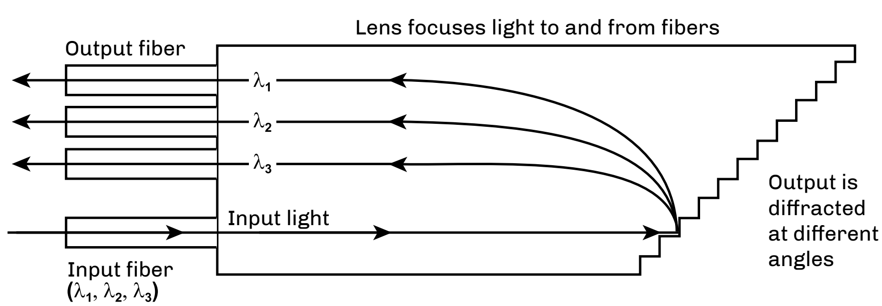


Optical switch examples

Multiplexing



Demultiplexing



Optical Splitters

Sometimes called couplers, optical splitters allow one or more input or output signals to be split into two or more fibers. Wavelength independent couplers (WICs) have the same attenuation in either direction and at multiple wavelengths.

When discussing the attenuation of an optical splitter, its theoretical value is a main concern. For example a 1:2 (50/50) split has a 3 dB loss. However, this 3 dB value does not consider fiber tolerances, splice losses when integrating splitters, and other types of mechanical loss.

Optical Branching Component (Wavelength Nonselective)

Insertion Loss			
Split Ratio	**Maximum**	**Minimum**	**Average**
1:2	4.2 dB	2.6 dB	3.4 dB
1:4	7.8 dB	5.4 dB	6.6 dB
1:8	11.4 dB	8.1 dB	9.7 dB
1:16	15.0 dB	10.8 dB	12.9 dB
1:32	18.6 dB	13.1 dB	15.8 dB
1:64*	22.8 dB	15.7 dB	19.2 dB

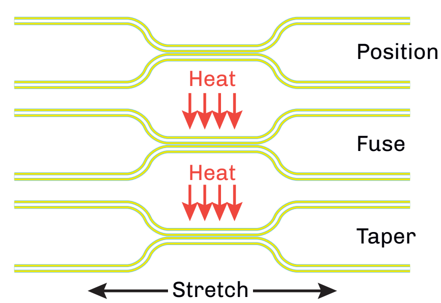
Operating wavelength range		
1310-nm window	1360 nm	1260 nm
1550-nm window	1580 nm	1480 nm

Asymmetric tap splitters branching component (wavelength nonselective) are also included in the G.671 standard with 20/80 (%), 10/90, 5/95, 2/98 and 1/99 ratios. All are listed for future study.

The G.671 optical components standard specifies minimum and maximum attenuation values for optical splitters operating over specified wavelengths. Wavelength independent couplers (WICs) must meet the attenuation values when measured bidirectionally using this wavelength spectrum.

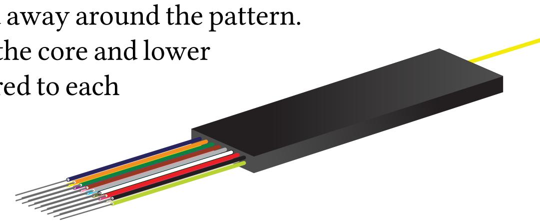
Fused Biconical Taper Splitters

This technique fuses a quantity of fibers together, allowing the cores to mix. By controlling the tension, fusion process, and power transmission level during manufacturing, precise tolerances can be maintained. Fused biconical tapers (FBTs) are nonreflective and normally used in small split counts or tapered splitters.



Planar Splitters

Planar splitters are compact, substrate-mounted optical branching circuits manufactured by laminating layers of substrate, cladding, and core glass together. A mask in the design of the split ratio (up to 128 outputs) is placed upon the core glass and the glass is etched away around the pattern.
A final layer of cladding glass is then flowed over the top of the core and lower cladding layers to encase the splitter. Optical fibers are adhered to each end of the planar splitter for the input and outputs.



WDMs and Bidi Devices

Wavelength division multiplexers (WDMs) combine two or more multiple wavelengths onto a single fiber. At the opposite end of the WDM link, the wavelengths are demultiplexed, separating the combined optical carriers and routing them to a receiver for processing. While WDM often describes the multiplexing of several optical wavelengths onto a single fiber, the term can also describe the multiplexing and demultiplexing of only two wavelengths, usually operating in different optical bands. WDM also allows for bidirectional transmission over one fiber.

WDM has proven to be an effective means of increasing capacity over existing fiber. Other WDM technologies include coarse wavelength division multiplexing (CWDM), wide wavelength division multiplexing (WWDM) and dense wavelength division multiplexing (DWDM).

- Combines and separates wavelengths.
- WDM.
    - Legacy 1310/1550 nm.
- Wide WDM
    - G.671.
- Coarse WDM
    - G.694.2.
- Dense WDM
    - G.692.

Optical Bidirectional Devices

Also known as bidi devices, these components incorporate a photodetector, a laser, and filters or lenses into a single package. These devices are used to more easily provide bidirectional transmission over a single fiber.

The key optical element of this device is the wavelength division multiplexing (WDM) filter. In order to achieve bidirectional transmission over a single fiber, one wavelength is required for each direction of transmission. This WDM element filters and separates the two wavelengths and directs them to and from the proper optical active device (laser or detector). Multimode devices typically use 850 and 1300 nm, while single-mode devices use 1310 and 1550 nm.

It's important to note that in order to properly test and troubleshoot a single fiber bidirectional transmission system, the transmitted power of the forward direction from the transmitter and the reverse (return) direction from the receiver must be measured to verify that both are working properly. The 1550-nm back channel on single-mode systems is sensitive to microbends and macrobends and could be problematic, even if the forward direction is functioning.

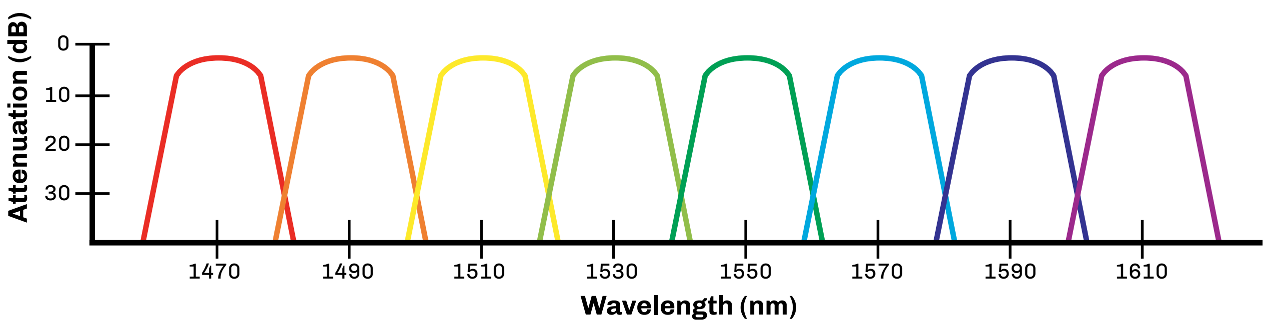
- Bidirectional transmission over one fiber.
- Incorporates laser and detector in a single package (diplexer).
- Integral WDM splits and combines wavelengths.
    - 850 nm and 1300 nm for multimode.
    - 1310 nm and 1550 nm for single-mode.

Coarse Wavelength Division Multiplexing

CWDM

Coarse WDM is a low-cost option for users who don't require the high power levels, close spacings and associated high costs of DWDM. With its fewer wavelengths, conventional spans, 20-nm spacings, low-cost SFP modules, and less expensive uncooled lasers, CWDM offers an alternative solution to many organizations wishing to expand their networks.

CWDM initially was used in the 1980s to allow up to four wavelengths to transmit signals within a single optical window (typically ±30 nm) over both single-mode and multimode fibers. The push to DWDM bypassed CWDM until the communications industry realized that CWDM provided a lower-cost alternative. The ITU G.694.2 standard specifies the wavelengths and channel spacing for CWDM transmission. Single-mode CWDM transmission takes place in the 1271 nm to 1611 nm operating range with 20-nm spacing between channels. While there are 18 single-mode CWDM channels specified, most systems currently have 4- or 8-channel designs.



CWDM Features

Single-mode networks, as specified in ITU-T G.694.2 and G.671 recommendations

Specified wavelengths (using 20-nm separation)

O-band: 1271 nm, 1291 nm, 1311 nm, 1331 nm, 1351 nm
E-band: 1371 nm, 1391 nm, 1411 nm, 1431 nm, 1451 nm*
S-band: 1451 nm*, 1471 nm, 1491 nm, 1511 nm, 1531 nm*
C-band: 1531 nm*, 1551 nm
L-band: 1571 nm, 1591 nm, 1611 nm

Multimode networks

Specified wavelengths

778 nm, 800 nm, 825 nm, 850 nm

ITU-T G.652D Single-mode Optical Fibers

The G.652D single-mode fiber was developed to allow for transmission in the E-band. G.652D fibers are ideal for transmitting wavelengths using the ITU-T G.694 specified CWDM channels. Known as reduced water peak, low water peak, or zero water peak fibers, they are compatible with the older G.652 fibers, and provide the option for future use of CWDM and DWDM in the E-band.

* At 1450 nm, the E-band ends and the S-band begins. At 1530 nm, the S-band ends and the C-band begins.

Dense WDM

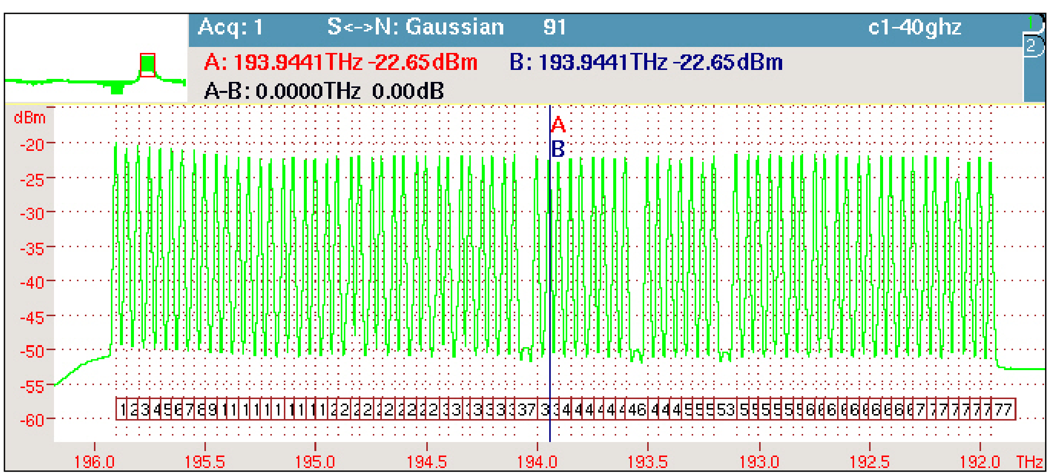
Dense wavelength division multiplexing (DWDM) is the transmission of different signals at multiple wavelengths with extremely tight channel spacings through the same optical fiber. The narrower the spacings, the more optical channels that can be multiplexed. WDM systems don't use a specific signal format, so any dedicated protocol (e.g., Ethernet, ATM) can be transmitted with a WDM system.

DWDM technology components and fibers are very mature, and modern DWDM systems can easily handle 40 or more channels at 100 or 50 GHz channel spacing. One fiber with 40 channels is the equivalent of a 40-fiber cable.

The ITU G.692 standard defines channel spacing options in DWDM systems. It specifies the optical wavelengths, attenuation, reflection, and dispersion values required. For DWDM systems, G.655 nonzero dispersion-shifted single-mode fiber is used to minimize attenuation and optical dispersion. This fiber is optimized for transmission and integration of EDFAs in the C-band (1530-1565 nm).

Currently, it is best to use DWDM in feeder routes. DWDM systems are expensive to implement due to the cost of the stringent optics involved. This can be offset by the cost of new physical plant construction. In most cases, today's designers would place a fiber rich cable with ribbon fibers, as material costs are very low compared to the cost of placement. It pays huge financial dividends to install as large a cable as possible in order to future-proof the system.

- ITU-T G.692.
    - 200 GHz (1.6 nm).
    - 100 GHz (0.8 nm).
    - 50 GHz (0.4 nm).
- Manufactured but not in standard.
    - 25 GHz (0.2 nm).
    - 12.5 GHz (0.1 nm).
- WDM-PON (NG-PON2) addresses DWDM in future systems.



64-channel DWDM system

Chapter 13 Review

1. True or false: Active devices are electro-optical components that actively manipulate electrons and photons to perform an intended function.

2. Fiber optic light sources must meet several important requirements. What characteristic of a light source would cause optical dispersion?

3. Since LEDs an couple more light into fibers with larger cores, what are they well suited for?

4. What is the modulation/data limit of an LED?

5. Which type of laser virtually has obsoleted the use of LEDs in fiber optic systems?

6. Which term describes the types of fibers used with VCSELs?

7. Lasers are rated through safety levels known as classes. Which of these is considered retina safe due to its low power level?

8. If the amount of received light at the receiver is too great, what must be done to resolve the problem?

9. If the transmitter has an output power level of −5 dBm and the receiver has a sensitivity of −30 dBm, what is the allowable physical loss?

Chapter 13 Review

10. What does the acronym LASER mean?

11. What does 3R designate?

12. What is another term for an optical splitter?

13. What is not required by passive fiber optic components?

14. What function do optical splitters perform?

15. Which class of WDM devices has a channel wavelength spacing of 20 nanometers?

16. Which class of WDM devices has channel wavelength spacings of 50, 100, or 200 GHz?

Student Notes

Chapter 14

Loss Budgets

By the end of this chapter, you will be able to:

- Define a link loss budget
- List the three main factors to consider when designing a fiber optic network
- Explain the importance of establishing a safety margin
- State the purpose of a “not to exceed” budget

Loss Budget Basics

One of the most important elements involved in designing a fiber optic system is the link loss budget. The link loss budget is a detailed calculation of the optical power available at the output of the transmitting source, the optical power required at the receiver's detector, and the dissipation or attenuation of optical power in the optical path between transmitter and receiver. It is a statement of how we intend to use the optical power that is available. Loss budgets are always planned with worst-case scenarios in mind.

Whenever possible, the designer should refer to fiber optic standards when writing system specifications. Through these standards, the designer can identify the attenuation for the components that will be used in order to calculate the loss budget for the fiber span. Every component in the system should be incorporated, including the optical cable, splices, and all connections.

The Impact of Attenuation

Attenuation applies to fiber, splices, connectors, splitters, and WDMs.

- If the optical power level is too low, the signal quality is degraded.
- If the power level is too high, the photo detector is affected, thereby degrading the signal quality.

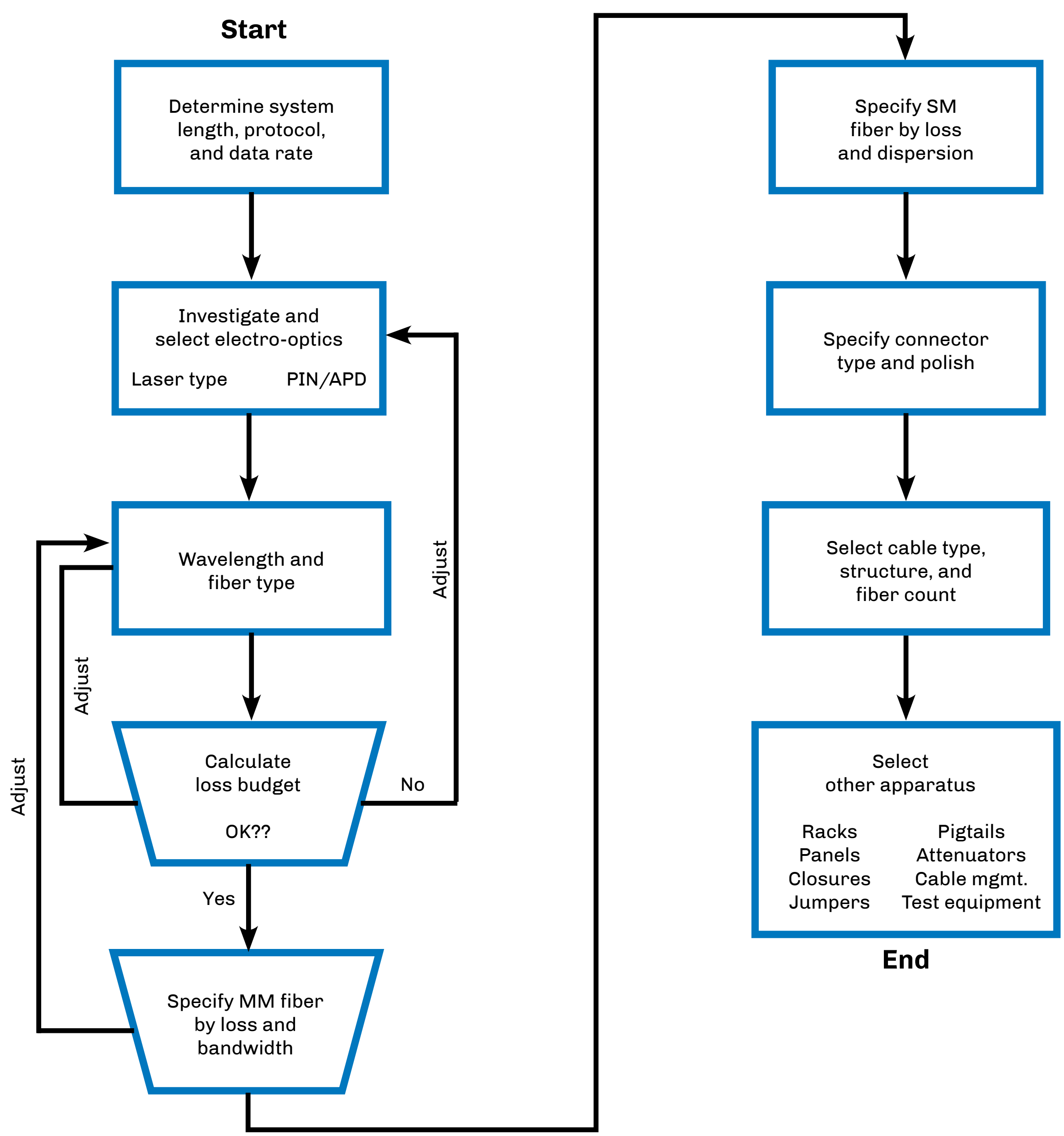
The minimum and maximum optical receive power levels should be reviewed and considered when creating an optical loss budget. The transmitter's optical power level and the loss in the outside plant will vary, so the actual power levels should be confirmed through optical power and optical loss testing. If the power level is too high, optical attenuator(s) must be added to decrease the received optical power level.

Loss Budget Design Flow Chart

Calculating a loss budget is critical part of designing a fiber optic link. Once the length of the span is determined and the signal type and protocol(s) selected, the focus turns to what fiber type, light source, photo diode, and operating wavelengths will be used.

For installers, a "not to exceed" budget helps to determine the end-to-end loss calculations as well as the maximum allowable loss for connections, splices, and passive devices.

- It should be a methodical, logical process.
- The length of the span must be determined, followed by selection of the signal type (voice, video, or data) and the protocol.



Design Options for Fiber Optic Networks

Fiber Types

Single-mode	G.652/G.652D	G.655	G.657
9/125	Standard single-mode 1310 nm	DWDM 1550 nm optimized	Bend insensitive

Multimode	Legacy (FDDI grade)	Laser-optimized	Bend-insensitive
50/125	Moderate bandwidth (OM2)	Highest bandwidth (OM3/4/5)	OM2/3/4/5
62.5/125	Lowest bandwidth (OM1)	Moderate bandwidth	N/A

Smaller fiber cores have lower attenuation and higher bandwidths. The exception is OM3 and OM4 laser-optimized multimode fibers designed for use with VCSEL light sources operating at 850 nm.

Wavelength

- Single-mode: 1310 nm, 1550 nm
- Multimode: 850 nm, 1300 nm
- The longer the wavelength, the lower the attenuation and the higher the allowable bandwidth. However, the higher the price as well.
  - The exception is laser-optimized multimode fibers designed for use with VCSEL light sources operating at 850 nm, where the bandwidth is higher.

Light Sources Used in Transmitters

- LED (surface or edge)
- Laser (DFB or Fabry-Perot)
- VCSEL (850 nm only)

Determine minimum and maximum optical power levels. The more powerful the source, the more power is launched into the fiber core. DFB, FP, and VCSEL lasers can be modulated faster than LEDs.

- Lasers launch more light into the fiber's core.
- Lasers have a small spatial spread.
- Lasers have narrower spectral widths.
- Lasers can be modulated faster than LEDs.

Detectors Used in Receivers

- Positive-intrinsic-negative (PIN)
- Avalanche photodiode (APD)

Determine minimum and maximum optical power levels. A more sensitive detector allows for greater loss margins. APD type are more sensitive, but amplify noise and are more expensive than PIN detectors. They cannot be used with analog systems.

- A more sensitive detector allows for greater loss margins.
- APD types are more sensitive, but amplify noise.

Safety Margin

Degradation of optical power is sometimes affected by factors unrelated to known losses. This factor of 3 dB (or 50%) attenuation is generally included in loss budget calculations but can also be greater than 3 dB.

- Degradation of power output over a period of time of 50% (3 dB).
- Environmental changes ±1 dB.*
- Future restoration splices.
- Connector loss on transmitter/receiver.**
- Other unknown future system attenuation.

Note: Many transmission equipment suppliers have suggested safety margins.

Attenuators

Attenuators may be required to increase attenuation of the optical power level received by the photodetector in the receiver. The designer must always review not only the minimum light level of the receiver, but also the maximum level as well.

During the design stage, the designer works with known or probable performance levels from various manufacturers' product specification sheets. From these specifications, a optical loss budget is derived. Actual performance tests of the transmission products and the physical plant should be made to verify actual loss levels.

The need for a different level of attenuator may be required due to the actual performance levels versus the designed level.

Evaluating Optical Input Levels

Input power levels to an optical receiver must fall within the dynamic range of the device in order to properly perform the optical to electrical conversion process required to restore the original transmitted signal information. Dynamic range is the optical input power range in which the receiver can successfully operate to reproduce the transmitted information signal. Many optical receivers possess automatic gain control (AGC) circuitry that enable the device to maintain a constant output over fluctuating, but limited, range of optical input power levels.

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* Optional; may be specified by equipment manufacturer.

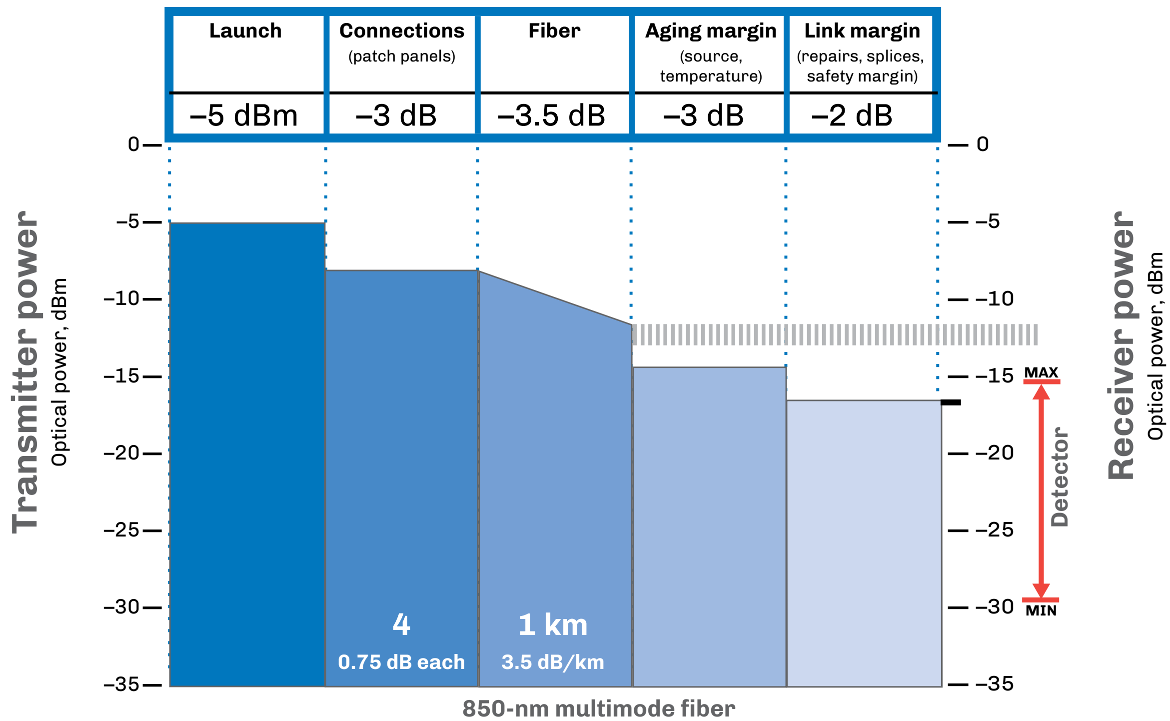
** Though usually included within the manufacturers' specifications, some manufacturers specify separately. It is best to verify with manufacturer.

Multimode System Budgets

The loss budget of an optical system is derived from the difference between the output light source at the transmitter and the photodetector's minimum sensitivity. This budget ensures designers that enough optical power is available to meet specific quality values, e.g., bit error rate.

From this system loss budget, the system margin, fiber, splice and connector losses are subtracted. The subsequent balance is the excess loss. Should this amount be greater than the maximum amount of light allowed, the photodiode in the receiver will be oversaturated. In this case, the use of an optical attenuator will be required.

This attenuation allows the power or link margin to fall between the minimum and maximum power levels of the receiver. Since this number is dependent upon the final installed loss measurements and not the specified engineering measurements, the attenuator may need to be determined at the final acceptance phase of the installation.



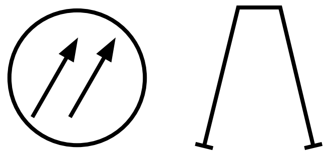
Example of a multimode transmission budget at 850 nm

In this example, a fiber link has been installed on a campus with the main cross connect (MC) panel in one building that connects to a intermediate cross connect (IC) at the building entrance. Thi s in turn is linked to a horizontal cross connect (HC) panel, which services a number of users with multiple user telecommunications outlet assemblies (MUTOAs), all of which have connections. Th e four locations have a

maximum 0.75 dB attenuation for each connection per the TIA-568 standard. Th e total span distance from the MC to the MUTOA is one kilometer (3,281 feet), and the system is a 1 Gb/s network with laser-optimized 50/125-µm OM-4 fi ber.

A 3 dB aging margin and a 2 dB repair margin have been added, which allows for degradation of the power level as well as possible additions, connections, or physical repairs in case of damage.

Multimode System Loss Budget



50/125

850 nm LED	850 nm VCSEL		1300 nm
− 15 dBm	− 5 dBm	Transmit power	− 12 dBm
− 30 dBm	− 30 dBm	Receiver minimum receive power w/PIN diode	− 25 dBm
15 dB	25 dB		13 dB
− 3 dB	− 3 dB	4 connections (1 @ each patch panel) @ 0.75 dB each	− 3 dB
12 dB	22 dB		10 dB
− 3.5 dB	− 3.5 dB	1 km cable loss @ 3.5 dB/km for 850 nm; 1 km cable loss @ 0.8 dB/km for 1300 nm	− 0.8 dB
8.5 dB	**18.5 dB**	**Link margin**	**9.2 dB**
3.6 dB	3.6 dB	Safety margin*	3.6 dB

Note: A loss budget is used to calculate the estimated attenuation to verify that enough optical power is available for proper operation. Once the end-to-end optical loss report is completed, it should be compared to the loss budget for any adjustments required, including the need for optical attenuators.

* 3 dB for 50% failure; 0.6 dB future restoration splices.

Multimode Wavelength Optimization

Fiber and Cable Combined		850 nm Loss	850 nm Bandwidth	1300 nm Loss	1300 nm Bandwidth
62.5/125	**OM1**	3.5 dB/km	200 MHz-km	1.5 dB/km	500 MHz-km
50/125	**OM2**	3.5 dB/km	500 MHz-km	0.8 dB/km	1,000 MHz-km
Laser-optimized 50/125	**OM3**	3.5 dB/km	2000 MHz-km	0.8 dB/km	500 MHz-km
Laser-optimized 50/125	**OM4**	2.5 dB/km	4700 MHz-km	0.8 dB/km	500 MHz-km
Laser-optimized 50/125	**OM5**	2.5 dB/km	4700 MHz-km	0.8 dB/km	500 MHz-km

Notice that as the core size decreases, the loss decreases and the bandwidth increases.

User Options

By varying the type of light source and detector used, manufacturers can provide different options for loss budgets. Example 1 uses a low-cost LED that can only handle a limited modulation rate (less than 622 Mb/s) along with a low-cost PIN photodiode in the receiver. This combination has the lowest cost and functions at both 850 nm and 1300 nm, but is bandwidth and modulation limited. Example 2 uses a much faster and higher power VCSEL light source in the transmitter with a low-cost PIN photodiode in the receiver. This is more common in Gigabit Ethernet or faster transmission products. Example 3 uses a Fabry-Perot laser and a PIN photodiode combination at 1300 nm, where there is no benefit in the use of a VCSEL, which is optimized for 850 nm transmission equipment.

Another task is to determine which wavelength and fiber structure is best for the bandwidth required.

Source		Detector		Loss Budget (dBm − dBm = dB)
LED	−15 dBm	PIN	−30 dBm	15.0 dB
VCSEL	−5 dBm		−30 dBm	25.0 dB
Laser	0 dBm		−30 dBm	30.0 dB

10/40/100 Gigabit Networks

As the data rates of fiber optic systems rise, physical network infrastructures must not only be reliable but also be flexible enough to support increasing speeds and changing demands. Next generation 10, 40, and 100 Gigabit networks place a demand on infrastructure and electronics not previously seen. To achieve high data rates with high signal quality, 40 and 100 Gb/s systems must use either parallel optics (multiple fibers/ribbons), WDM technologies, and/or advanced modulation formats.

From a loss budget perspective, the fiber type and termination method are key factors in maintaining system performance. Not only is the attenuation (dB/km) of the fiber critical, the loss and reflectance from the chosen termination method will also have a major impact. Loss has always been and will remain a key issue as it relates to power. Once a network has more loss than power, it is no longer operational.

Year	Ethernet Speed	IEEE #	Designation	IEC #	Max Link Length	Max Insertion Loss
1993	Ethernet	802.3	10BASE-FL	OM1/2	2 km	7.8 dB
1995	Fast Ethernet	802.3u	100BASE-FX	OM1/2	2 km	6 dB
1998	1 Gigabit Ethernet	802.3z	1000BASE-SX	OM1/2	550 m	4.5 dB
2002	10 Gigabit	802.3ae	10GBASE-SR	OM3	300 m	2.6 dB
2010	40 Gigabit	802.3ba	40GBASE-SR4	OM3	100 m	1.9 dB
				OM4	150 m	1.5 dB
2010	100 Gigabit	802.3ba	100GBASE-SR10	OM3	100 m	1.9 dB
				OM4	150 m	1.5 dB
		802.3bm	100GBASE-SR4	OM4	100 m	1.9 dB

Courtesy Belden

Maximum Cabling Distances

Cable type	1 GbE		10 GbE		40/100 GbE	
	Loss	Length	Loss	Length	Loss	Length
OM3	4.5 dB	1000 meters	2.6 dB	300 meters	1.9 dB	100 meters
OM4/5	4.8 dB	1100 meters	3.1 dB	400 meters	1.5 dB	150 meters

Courtesy Belden

- As data rates increase, the effects of modal dispersion limit the transmission distance.
  - To maintain a high signal quality, the allowable path loss budget decreases.
  - Connector losses are lower when using VCSELs instead of LEDs.
  - High bandwidth laser-optimized fibers allow longer distances.
- Decrease the data rate per fiber to extend transmission distance.
  - CWDM.
  - Parallel optics – multiple or ribbon fibers and MPO connectors).

Multimode Fiber Size Compatibility

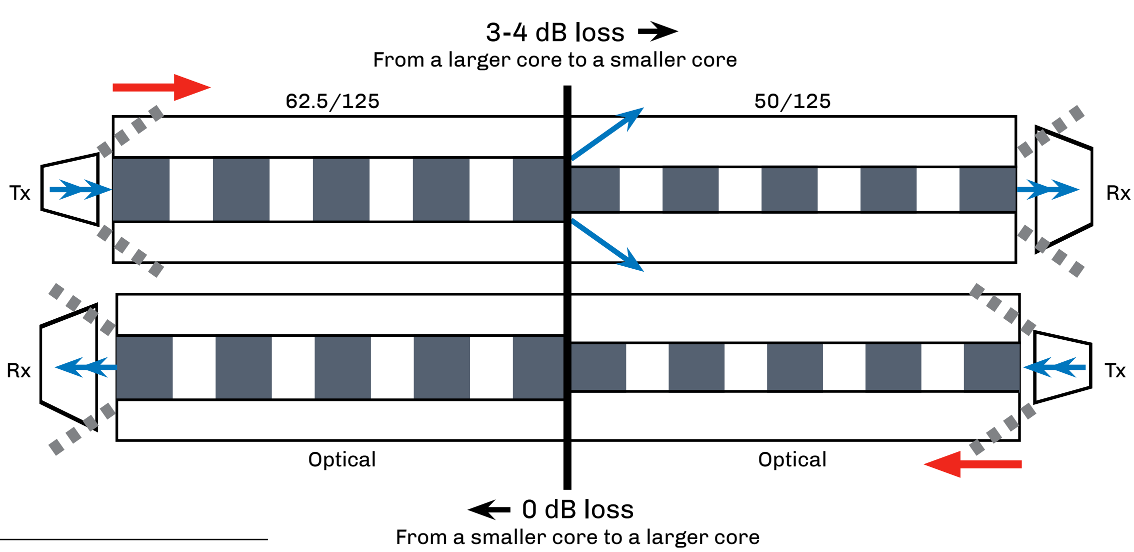
With the increased use of higher bandwidth 50/125 OM3 and OM4 multimode fibers, there is a high chance these could be cross mated with legacy 62.5/125 OM1 fibers. There are four issues that affect the attenuation of the mismatched link.

1. The diameter of the 50-µm core is smaller than the 62.5-µm core, which will create higher losses.
2. The numerical aperture of 50/125 micron is .20 and 62.5/125 fiber is .275. If the transmission occurs from the 50/125 fiber to the 62.5/125, the only loss should be that caused by the Fresnel surface reflections.
3. If the transmission occurs from the larger 62.5/125 to the smaller 50/125, the loss will be higher.
4. If a transmitter has a VCSEL light source, there is less attenuation as most of the optical energy is in the center of the fiber's cores.

		Transmitting fiber						
		50 µm			62.5 µm			9 µm
		Laser	LED		Laser	LED		
			OFL	RML		OFL	RML	
Receiving fiber	50 µm (NA = 0.20)	0 dB	0.25 dB	0.09 dB	0 dB	3.5 dB	3.2 dB	0.03 dB
	62.5 µm (NA = 0.275)	0.07 dB	0.36 dB	0.36 dB	0.4 dB	0.31 dB	0.28 dB	0.05 dB
	9 µm (NA = 0.13)	3.4 dB	17.7 dB	16.0 dB	2.6 dB	21.2 dB	20.8 dB	0.08 dB

OFL = Overfilled launch RML = Restricted mode launch

The tests used a two jumper test method with an worst case overfilled launch (OFL) condition and a restricted mode launch (RML) condition using either a 50 or 62.5 mode filter. The RML technique removed higher order modes from the multimode fibers, making up to a 5 dB difference in the test results. The single-mode to single-mode tests only used the RML technique as the light source was a FP laser.



* The loss values include one mated connection.

“Not to Exceed” Chart for Multimode Spans

“Not to exceed” spreadsheets are great for installers, contractors and inspectors. They identify the total loss values of the optical cable, connectors, and splices, and help to easily pinpoint fiber spans that are out of specification. Contractors and installers normally provide optical loss testing using the stabilized light sources and calibrated optical power meter to measure the attenuation levels between the transmission equipment's patch panels to demonstrate proof of performance. These tests normally are performed bidirectionally and at 850 nm and 1300 nm, based on TIA-568 specifications for 62.5/125 graded-index multimode fibers for a given span length.

There is also a column for the additional connection loss (see Note 1), based on performing fiber optic testing when using the insertion loss technique as specified in TIA-455-171-A, test method B (attenuation by substitution measurement), and TIA-526-14B, method A (optical power loss measurements of installed multimode fiber plant). The final measurement in this column is a “not to exceed” number in dB.

Feet	Meters	850 nm (3.5 dB/km)	With patch panel	1300 nm (1.5 dB/km)	With patch panel
100	30	0.10 dB	0.85 dB	0.05 dB	0.80 dB
200	61	0.21 dB	0.96 dB	0.10 dB	0.85 dB
300	91	0.32 dB	1.07 dB	0.14 dB	0.89 dB
400	122	0.42 dB	1.17 dB	0.19 dB	0.94 dB
500	152	0.53 dB	1.28 dB	0.23 dB	0.98 dB
600	183	0.65 dB	1.40 dB	0.28 dB	1.03 dB
700	213	0.74 dB	1.49 dB	0.32 dB	1.07 dB
800	244	0.85 dB	1.60 dB	0.37 dB	1.12 dB
900	274	0.97 dB	1.72 dB	0.42 dB	1.17 dB
1000	305	1.06 dB	1.81 dB	0.46 dB	1.21 dB
1250	381	1.34 dB	2.09 dB	0.58 dB	1.33 dB
1500	457	1.59 dB	2.34 dB	0.69 dB	1.44 dB
1750	533	1.84 dB	2.59 dB	0.80 dB	1.55 dB
2000	610	2.18 dB	2.93 dB	0.92 dB	1.67 dB
2500	762	2.69 dB	3.44 dB	1.15 dB	1.90 dB
3000	914	3.21 dB	3.96 dB	1.38 dB	2.13 dB
3281	1000	3.50 dB	4.25 dB	1.50 dB	2.25 dB
4000	1219	4.27 dB	5.02 dB	1.83 dB	2.58 dB
5000	1524	5.38 dB	6.13 dB	2.29 dB	3.04 dB
5280	1609	5.64 dB	6.39 dB	2.42 dB	3.17 dB

Notes:

1. Attenuation numbers are rounded to the highest 1/100th of a dB.
2. With patch panel column includes additional 0.75 dB as specified in TIA-568 for connection not included in light source and power meter reference using two reference jumpers and additional sleeve.

Single-mode Wavelength Optimization

By changing the wavelength, the designer can take advantage of the different loss, bandwidth and dispersion characteristics that optical fibers offer.

	9/125 G.652/652D* (OS1/OS2) Fiber		9/125 G.655 Fiber**	
	1310 nm	**1550 nm**	**1310 nm**	**1550 nm**
Loss	0.5 dB/km	0.4 dB/km	0.5 dB/km†	0.35 dB/km
Dispersion*	0.092 ps/nm^2•km	17 ps/nm•km†	−7 to 25 ps/nm•km†	0.1 ps/nm•km
Optimized for	Minimal dispersion and moderate loss	High dispersion and lowest loss	High dispersion and moderate loss	Lowest dispersion and lowest loss

* Per ITU-T G.652A, Table 1, 2005.
** Per ITU-T G.655A, Table 1, 2003.
† Calculations based upon manufacturer's general specifications.

With single-mode fibers, the designer must be sure to match the wavelength and perform the bandwidth calculation. While attenuation may decrease, the optical bandwidth would also decrease without nonzero dispersion-shifted (NZDS) fiber optimized for use at 1550 nm.

User Options

By varying the type of light source and detector used, manufacturers can provide different options for loss budgets. In examples 1 and 3 below, the only change was to add the more sensitive APD photodiode in the receiver. Example 2 uses a much higher powered DFB laser and the less sensitive PIN detector. This combination is used with analog AM CATV systems due to problems with noise.

Another related task is to select which wavelength is best for attenuation, dispersion, and WDM applications.

Source		Detector		Loss Budget (dBm − dBm = dB)
Laser	0 dBm	PIN	−30 dBm	30.0 dB
	+10 dBm		−17 dBm	27.0 dB
	0 dBm	APD	−40 dBm	40.0 dB

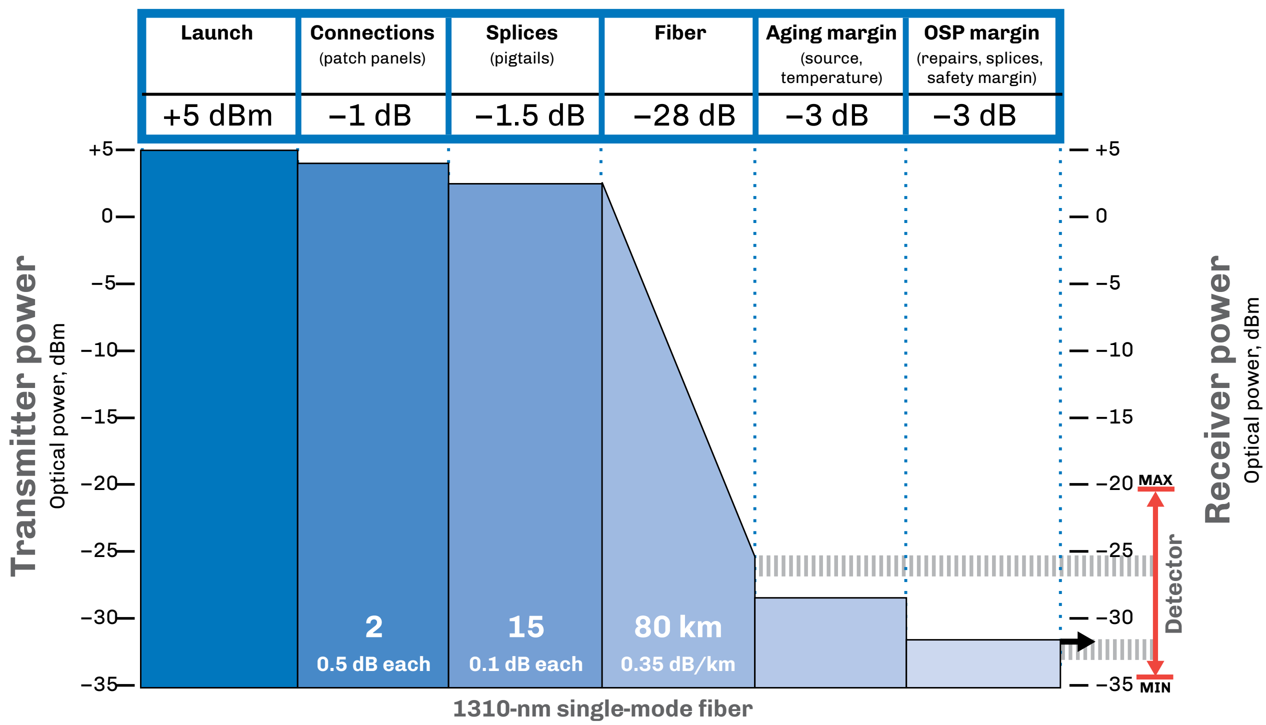
Single-mode System Budgets

The loss budget of an optical system is derived from the difference between the output light source at the transmitter and the photodetector's minimum sensitivity. This budget ensures designers that enough optical power is available to meet specific quality values, e.g., bit error rate.

From this system loss budget, the system margin, fiber, splice and connector losses are subtracted. The subsequent balance is the excess loss. Should this amount be greater than the maximum amount of light allowed, the photodiode in the receiver will be oversaturated. In this case, the use of an optical attenuator will be required.

This attenuation allows the power or link margin to fall between the minimum and maximum power levels of the receiver. Since this number is dependent upon the final installed loss measurements and not the specified engineering measurements, the attenuator may need to be determined at the final acceptance phase of the installation.

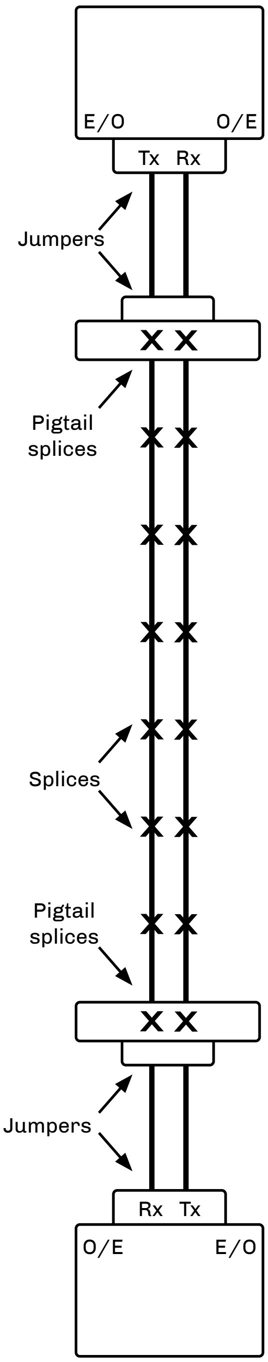
When determining loss budgets using WDM technologies, the worst-case loss budget at each wavelength must be used to determine maximum transmission distance.

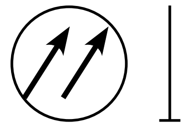


Example of a single-mode transmission budget at 1310 nm

- Address receiver range.
- Address actual Tx level.
- 80 km.
- Fiber loss.

Single-mode System Loss Budget





Telco/Utility Example			CATV Example
0 dBm	+ Transmitter power		10 dBm
− 40 dBm	− Receiver sensitivity*		− 20 dBm
40 dB			30 dB
− 1.0 dB	2 connections (1 @ each patch panel)		− 1.0 dB
39.0 dB	@ 0.5 dB each		29.0 dB
− 0.8 dB	8 splices @ 0.1 dB ea		− 0.8 dB
38.2 dB			28.2 dB
− 16.8 dB	42 km cable loss @ 0.4 dB/km for 1310 nm	42 km cable loss @ 0.25 dB/km for 1550 nm	− 10.5 dB
21.4 dB	**Link margin**		**7.7 dB**
	Safety margin*		5 dB

Note: Single-mode systems designed for long spans and used for short or moderate spans may require optical attenuators to prevent the receiver's photodetector from oversaturation. Check your system specifications for both minimum and maximum receive levels. A loss budget is used to calculate the estimated attenuation to verify that enough optical power is available for proper operation. Once the end-to-end optical loss report is completed, it should be compared to the loss budget for any adjustments required, including the need for optical attenuators.

* Includes 3 dB for 50% failure 2 dB for 10 restoration splices @ 0.2 dB each.

"Not to Exceed" Chart for Single-mode Spans

"Not to exceed" spreadsheets are great for installers, contractors, and inspectors. They identify the total loss values of the optical cable, fiber, connectors, splices, and splitters, and help to easily pinpoint fiber spans that are out of specification. Contractors and installers normally provide optical loss testing using the stabilized light sources and calibrated optical power meter to measure the attenuation levels between the transmission equipment's patch panels to demonstrate proof of performance. These tests normally are performed bidirectionally and at 1310 nm and 1550 nm. In single-mode systems these tests also are performed using the OTDR.

Based on generic specifications for G.652 single-mode fibers for a given span length for 1310-nm and 1550-nm wavelength-based systems.

In addition, a column has been added for the additional connection loss (1) based on performing fiber optic testing when using the insertion loss technique as specified in TIA-455-171-A, test method B (attenuation by substitution measurement) in this column is a "not to exceed" number in dB.

km	1310 nm (0.4 dB/km)	+ Splice qty x 0.1 dB	With patch panel	Total	1550 nm (0.25 dB/km)	+ Splice qty x 0.1 dB	With patch panel	Total
1	0.4	0.2	0.5	1.15	0.25	0.2	0.5	0.95
2	0.8	0.2	0.5	1.50	0.50	0.2	0.5	1.30
3	1.2	0.2	0.5	1.90	0.75	0.2	0.5	1.45
4	1.6	0.2	0.5	2.30	1.00	0.2	0.5	1.70
5	2.0	0.2	0.5	2.70	1.25	0.2	0.5	1.95
10	4.0	0.3	0.5	4.80	2.50	0.3	0.5	3.30
15	6.0	0.4	0.5	6.90	3.75	0.4	0.5	4.65
20	8.0	0.5	0.5	9.00	5.00	0.5	0.5	6.00
25	10.0	0.6	0.5	11.10	6.25	0.6	0.5	7.35
30	12.0	0.6	0.5	13.10	7.50	0.6	0.5	8.60
35	14.0	0.7	0.5	15.20	8.75	0.7	0.5	9.95
40	16.0	0.8	0.5	17.30	10.00	0.8	0.5	11.30
45	18.0	0.9	0.5	19.40	11.25	0.9	0.5	12.65
50	20.0	1.0	0.5	21.50	12.50	1.0	0.5	14.00
55	22.0	1.0	0.5	23.50	13.75	1.0	0.5	15.25
60	24.0	1.1	0.5	25.60	15.00	1.1	0.5	16.60
70	28.0	1.3	0.5	29.80	17.50	1.3	0.5	19.30
80	32.0	1.4	0.5	33.90	20.00	1.4	0.5	21.10
90	36.0	1.5	0.5	38.00	22.50	1.5	0.5	24.50
100	40.0	1.7	0.5	42.20	25.00	1.7	0.5	27.20

Notes:

1. Attenuation numbers are rounded to the highest 1/100th of a dB.
2. With patch panel column includes additional 0.5 dB as specified in ITU-T G.671 for connection not included in light source and power meter reference using two reference jumpers and additional sleeve.
3. Adjust splice loss to meet your requirements. Column is based on 0.1 dB/splice as specified in the Telcordia GR-20 and outside plant standard.
4. Based on the inclusion of two pigtail splices and 6-km cable spans.

Loss Budgets for FTTx Networks

Loss budgets for active Ethernet networks are based on a standard point-to-point format. This also applies to individual passive optical network (PON) spans before or after an optical splitter. Splitter attenuation must also be included in the loss budget, as it is the factor that limits the distance of a PON to 20 kilometers (12 miles). The loss through a single 1:32 splitter is equal to the attenuation of a 40-kilometer (26 mile) span.

General Rules for PON

1. Length of fiber is less than or equal to 20 km.
2. Loss should be no greater than 30 dB for Class A, Class B, and Class C and greater than 30 dB for Class B+ and Class C+.
3. Splitters are bidirectional wavelength independent couplers (WIC).
    a. Losses are consistent upstream/downstream at 1310/1490/1550 nm.
    b. ODN splitter loss is calculated at 15.8 dB for 1:32 splitters, and 19.2 dB for 1:64 splitters.

General Rules for PON and Active Ethernet

1. Splices are less than 0.1 dB per Telcordia GR-20 and GR-765.
2. Connectors are less than 0.5 dB per ITU-T G.671.
3. G.652 single-mode fiber with 1490 nm rating.
4. Downstream attenuation is calculated at 1550 nm (0.3 dB/km).
5. Upstream attenuation is calculated at 1310 nm (0.4 dB/km).
6. RF overlay applications add 1.0 dB for the WDM.

General Rules for Active Ethernet

1. Length of span limited by single-mode loss and dispersion; 100-kilometer spans are achievable.
2. For bidirectional (BX) transmission, verify wavelength (1310 nm, 1490 nm, 1550 nm) and fiber options (G.652, G.655) with system suppliers.
3. Dual fiber (LX) can operate at 1310 nm or 1550 nm based on distance, attenuation, and chromatic dispersion.
4. SFP (GbE), SFP+ (10GbE), and XFP (10GbE) are common interfaces.

- PON criteria.
    - Identify expected OSP losses.
    - Select ODN class required.
        - Tx/Rx cards.
    - Address splitter attenuation.
    - Upstream and downstream fiber attenuation.

- Active Ethernet.
    - Can be longer than 20 km.
    - No splitter losses.
    - Single fiber bidirectional (BX).
    - Dual fiber unidirectional (LX).

PON Architectures

Transmitter and Receiver Specifications

The charts below show a typical G-PON Class A (5-20 dB), Class B (10-25 dB), and Class C (15-30 dB) transmitter and receiver optical power recommendations for services provided to the customer over the ODN. The fiber, splices, connector, and splitter losses need to subtracted from the loss budget, which leaves a sufficient safety margin to address future restorations and transitions.

Downstream Power Levels

In this example of the downstream transmission from the OLT to the ONT, the center wavelength of the spectrum is 1490 nm. Three power classifications are provided from the lower power Class A to the higher power class C cards. Not shown are classes B+, C+, and C++ for larger split configurations.

G.984.2 Optical Interface Parameters at 2,488 Mb/s

Items	Unit	Single fiber		
OLT transmitter				
Nominal bit rate	Mb/s	2488.32		
Operating wavelength	nm	1480-1500		
ODN class		A	B	C
Mean launched power min	dBm	0	+5	+3
Mean launched power max	dBm	+4	+9	+7
ONT receiver				
Minimum sensitivity	dBm	−21	−21	−28
Minimum overload	dBm	−1	−1	−8

Upstream Power Levels

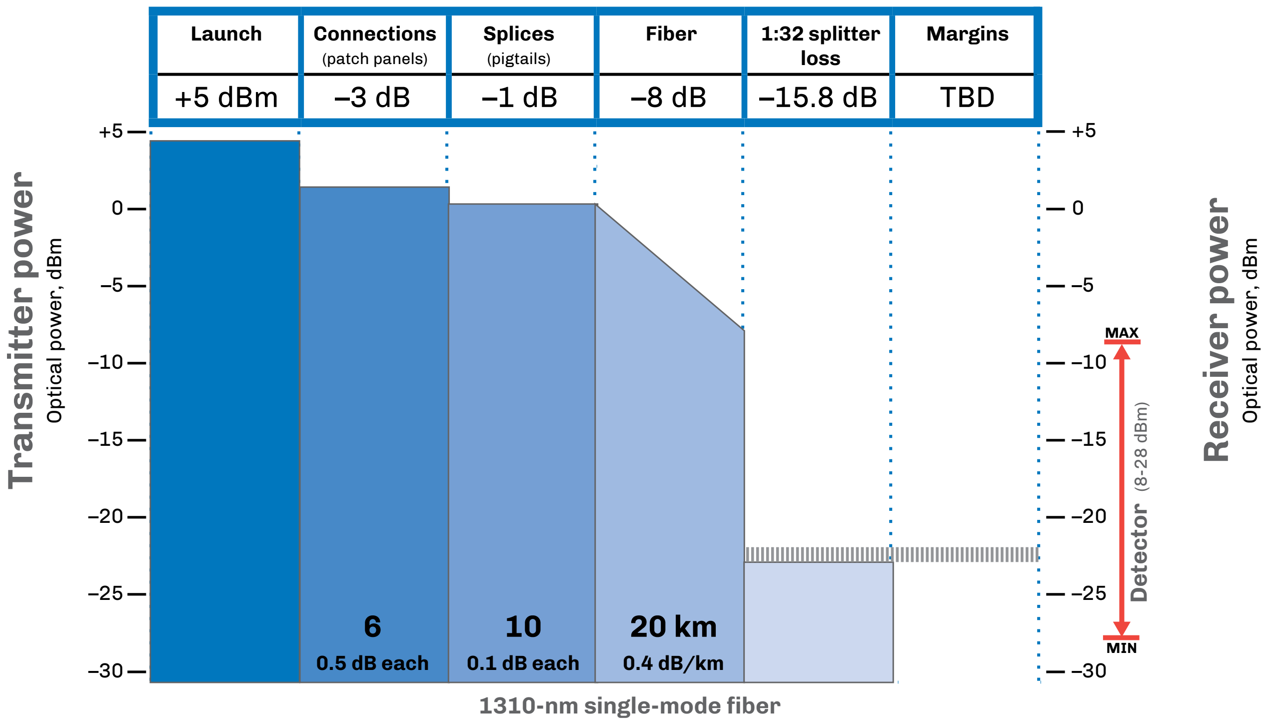
In this example of the upstream transmission from the ONT to the OLT, the center wavelength of the spectrum is 1310 nm. Three power classifications are provided from the lower power Class A to the higher power class C cards. Not shown are classes B+, C+, and C++ for larger split configurations.

G.984.2 Optical Interface Parameters at 1,244 Mb/s

Items	Unit	Single fiber		
ONT transmitter				
Nominal bit rate	Mb/s	1244.16		
Operating wavelength	nm	1260-1360		
ODN class		A	B	C
Mean launched power (min)	dBm	−3	−2	+2
Mean launched power (max)	dBm	+2	+3	+7
OLT receiver				
Minimum sensitivity	dBm	−24	−28	−29
Minimum overload	dBm	−3	−7	−8

Both the OLT and ONT's receivers have both the minimum and the overload optical power levels. Designers need to select the card classification based on their loss budgets. Technicians need to confirm the power levels upon activation.

P2MP System Budgets



P2MP "Not to Exceed" Charts

- Fiber attenuation is 0.4 dB/km at 1310 nm and 0.35 dB/km at 1550 nm.
- Splice attenuation is 0.1 dB per splice.
- Patch panel attenuation is 0.5 dB per connection.

1310 nm

km	Fiber	Splices	Patch panel	1:32 splitter	Total, in dB
1	0.4	0.4	3.5	15.8	20.1
5	2.0	0.4	3.5	15.8	21.7
10	4.0	0.6	3.5	15.8	23.9
15	6.0	0.8	3.5	15.8	26.1
20	8.0	1.0	3.5	15.8	28.3

1550 nm

km	Fiber	Splices	Patch panel	1:32 splitter	Total, in dB
1	0.3	0.2	3.5	15.8	19.8
5	1.5	0.4	3.5	15.8	21.2
10	3.0	0.6	3.5	15.8	22.9
15	4.5	0.8	3.5	15.8	24.6
20	6.0	1.0	3.5	15.8	26.3

Chapter 14 Review

1. Why do you need a safety margin factor in your loss budget?

2. What does the safety margin include and account for?

3. What are the three main factors that a designer has to consider when designing a fiber optic network?

4. Does attenuation increase or decrease when shifting to a longer wavelength?

5. What can a designer change to take advantage of the fiber's different loss, bandwidth, and dispersion characteristics?

6. Manufacturers can provide different options for loss budgets by varying the type of light source and what?

7. The designer must always review the minimum and maximum light levels of what?

8. What may be required to increase attenuation of the optical power level received by the photodetector in the receiver?

9. What information about an optical system is derived from the difference between the optical output at the transmitter and the photodetector's minimum sensitivity?

Chapter 14 Review

10. In what type of fiber does limiting differential mode delay (DMD) increase bandwidth?

11. Per ITU-T G.984, what is the maximum distance for a PON network?

12. True or false: A loss budget is used to calculate the attenuation to verify that enough power is available for operation.

13. What does a “not to exceed” loss budget calculation include?

14. What can a “not to exceed” loss budget be used for?

Student Notes

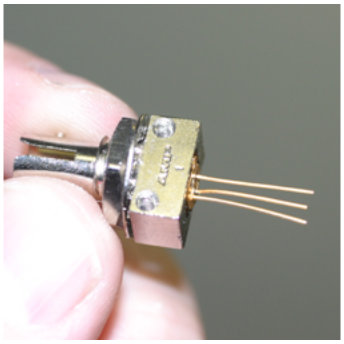
Chapter 15

Safety Best Practices

By the end of this chapter, you will be able to:

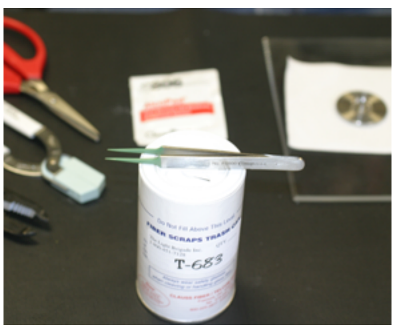
- Summarize best practices for a safe workplace

Fiber Optic Safety Concerns

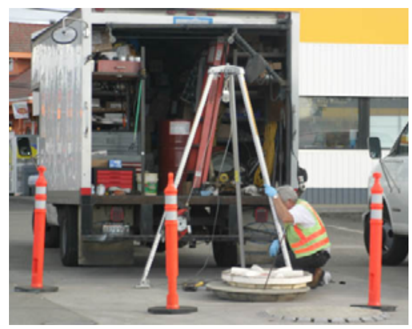


Lasers
Test equipment
Amplifiers
Tx/Rx
FOCS

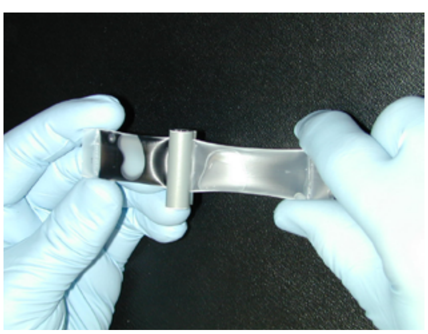
Installation
Aerial • High voltage
Underground
Confined spaces
Indoors



Fiber
Fiber handling
Work area



Basic safety procedures
Ladder safety
Personal protective equipment



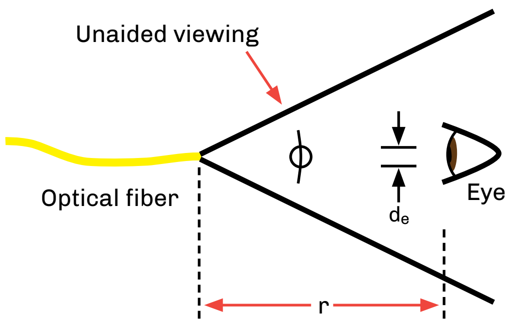
Chemicals
SDS
WHMIS

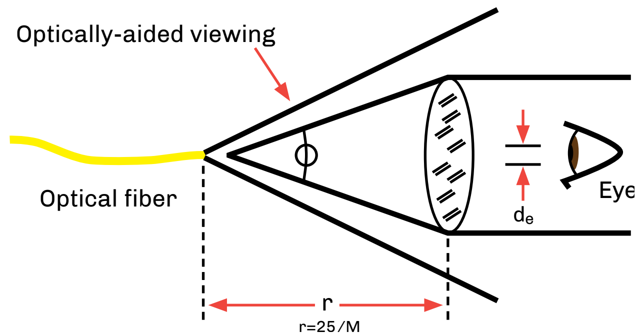
Visual Safety Using Fiber Optic Sources

The following diagrams show how light energy spreads once the optical beam exits the optical fiber. The angle of this spreading is determined by the numerical aperture (NA) of the optical fiber.

The nominal ocular hazard zone (NOHZ) is the distance from the source, fiber, or connector to the eye. The optical power level must not exceed the maximum permissible exposure (MPE), which is the maximum level of optical power that can be safely used. Exposure beyond the MPE can result in injury or biological changes in the eye or skin. The MPE is used to determine the nominal hazard zone (NHZ), the optical density (OD), and the accessible emission limit (AEL).

- Nominal ocular hazard zone (NOHZ).
    - Distance from source, fiber, or connector to the eye.
- Maximum permissible exposure (MPE).
    - Maximum level of optical power that can be safely used.
    - Determines NHZ, OD, and AEL.





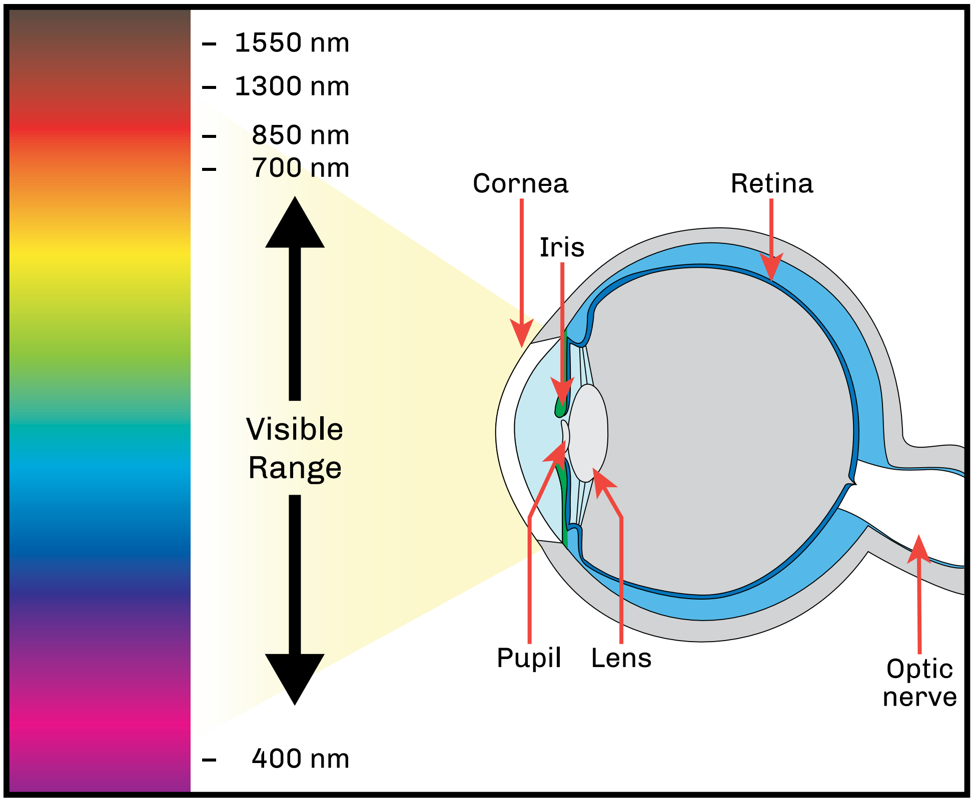
This example shows how the distance from the source, fiber or connector can determine the amount of optical radiation that is received by the eye. The closer to the fiber, the more optical power.

When using microscopes, the optical beam can be collimated, or refracted to increase the optical density to the eye. New digital scopes are safer, as they show the visual image on their LCD screen.

Laser Safety Standards

1. **North America:** ANSI Z.136.2, "Safe Use of Fiber Optic and Free-space Optical Communication Systems Utilizing Laser Diodes and LED Sources"
2. **International:** IEC 60825-2, "Safety of Optical Fiber Communication Systems"

Wavelength and The Eye



Visible and Near Infrared (400 nm – 1400 nm)

- Light in these wavelength ranges cause retinal damage.
- Focusing effects of the lens and cornea increase the irradiance on the retina.
- Can be permanent if the laser has a high enough power level.

Mid Infrared, Far Infrared, and Far UV (1400 nm – 1 mm)

- The cornea absorbs the light of these wavelengths.
- Causes a temporary denaturation of proteins in the cornea caused by the temperature rise.
- Corneal tissues can regenerate.
- 1550-nm systems apply to this range.

Most fiber optic communication systems (FOCS) use lasers that are low power and rated Class 1. The most dangerous FOCS applications are those using erbium-doped fiber amplifiers (EDFAs) and Raman amplifiers.

Laser Classifications

The ANSI Z136.2 standard from the American National Standards Institute addresses the concerns of organizations and personnel involved with the use of fiber optic communications systems. "Safe Use of Fiber Optic and Free-space Optical Communications Systems Utilizing Laser Diodes and LED Sources," published by Laser Institute of America (LIA), Orlando, Florida, www.laserinstitute.org.

The international laser safety standard is IEC 60825-2, "Safety of optical fibre communications systems".

The safety practices for working with fiber optics are similar to when working with electricity. Like with electricity, the hazards aren't visibly evident. Most lasers used with fiber optic transmitters and test equipment operate in the infrared range where the beam is invisible to the eye. Viewing an optical beam does not cause pain. The iris of the eye will not close involuntarily as when viewing a bright light.

Type	Risk or Injury	Risk Level
Class 1	Low energy levels, not hazardous to skin or eyes. Safe during normal operation.	Low
Class 1M	Safe during normal operation. May cause eye injury if viewed through optical instruments.	Low-Medium
Class 2	Visible wavelengths only, blink response provides eye safety. Will not burn skin.	Low-Medium
Class 2M	Visible wavelengths only, blink response provides eye safety for unaided viewing. May cause eye injury if viewed through optical instruments. Will not burn skin.	Medium
Class 3R	Transitional zone between safe and hazardous laser products. Direct viewing of beam may be hazardous as well as certain specular reflections.	Medium-High
Class 3B	Direct viewing and specular reflections can cause eye injury. Diffuse reflections usually safe.	High
Class 4	Can cause severe skin and eye injury through any direct exposure, specular reflections and sometimes from diffuse reflections. Often a fire hazard as well.	Extreme

- Most communication systems use Class 1 lasers. These are considered eye safe because of their low power levels.
- Optical amplifiers can be Class 3 or Class 4 and require optical safety laser eyewear.
- Visible lasers are Class 2 or Class 3R (restricted).
- The best protection against eye damage is to NOT LOOK into the fiber or transmitter ports.

Several factors can determine the safe use of optical sources and fibers. These include:

- Optical wavelength — The shorter the wavelength, the more dangerous.
- Optical power (mW) — Lasers emit more power than LEDs.
- Time exposure.
- Distance from the end of the fiber to the eye.
- Ribbon fiber (amount of fibers) — Closely spaced.
- Optical multiplexing (DWDM) — Use Class III optical amplifiers.

Working with Lasers

Accessible Emission Limits (Maximum Power or Power Range)

The maximum power levels or ranges presented below are appropriate for exposure duration's equivalent to a whole working day ($3x10^4$ seconds). These levels are given for Classes 1, 2, and 3 lasers.

Operating Wavelength	Light Band	Class 1 Retina Safe*	Class 2 Visible Only	Class 3 High Power
670 nm	Visible	≤0.024 mW ≤−16 dBm	≤0.024 mW ≤1 mW ≥−16 dBm <0 dBm	≤1 mW ≤500 mW ≥0 dBm <26.98 dBm
850 nm	Infrared	≤0.25 mW ≤−6 dBm	N/A	≤0.25 mW ≤500 mW ≥−6 dBm <26.98 dBm
1310 nm	Infrared	≤4.9 mW ≤6.9 dBm	N/A	≤4.9 mW ≤500 mW ≥6.9 dBm <26.98 dBm
1490 nm	Infrared	≤9.6 mW ≤9.8 dBm	N/A	≤9.6 mW ≤500 mW ≥9.8 dBm <26.98 dBm
1550 nm	Infrared	≤9.6 mW ≤9.8 dBm	N/A	≤9.6 mW ≤500 mW ≥9.8 dBm <26.98 dBm
1625 nm	Infrared	≤9.6 mW ≤9.8 dBm	N/A	≤9.6 mW ≤500 mW ≥9.8 dBm <26.98 dBm

Potential Problem Areas

- During inspection of fiber ends with microscope, which collimates the laser beam.
- When inspecting a fiber or connector, be sure that the inspection scope has an adequate safety filter and that the transmitter is off.
- Looking into the output ports of an optical transmitter. Many CATV lasers and optical amplifiers are classified as Class 3 lasers and extra precaution should be used when working with these sources. Optical ports should always be capped when not in use.
- When terminating high-powered lasers used on test equipment, be aware of the location of access to the other end.
- Problem areas.
  - Inspecting fibers or connectors.
  - Fiber preparation.
  - Transmitter ports.
  - Ribbon fibers.
  - Optical test equipment.
  - Public access.
  - Optical amplifiers.
  - Visible lasers.

Lasers

Class	Type	Wavelength
Class 1	VCSELs	850 nm
	Fabry-Perot, DFB	1310 nm
		1550 nm
		1625 nm
Class 2	VCSEL	632-670 nm
Class 3R	VCSEL	

Optical amplifiers

Class	Type
Class 3	EDFA or Raman
Class 4	Combined EDFA and Raman

* Per Z136.2, "a Class 1 laser system is considered to be incapable of producing damaging radiation levels during operation and, therefore, is exempt from any control measures." This is due to their low optical power levels.

Safety Eyewear

Protective glasses or goggles with appropriate filters can protect the eyes from laser light. The protective goal of laser eyewear is such that if laser radiation strikes the lens portion of the eyewear, the lens will reduce or completely block any transmitted radiation to below the MPE level. Laser protective eyewear is rated for OD which is the base-10 logarithm of the attenuation factor by which the optical filter reduces beam power. For example, eyewear rated as OD 3 will reduce the beam power at the specified wavelength range by a factor of 1,000. One can think of OD as similar to SPF for sunblock. Eyewear must be selected for the specific type of laser, to block or attenuate in the appropriate wavelength range.

Courtesy Laservision USA

Courtesy 3M

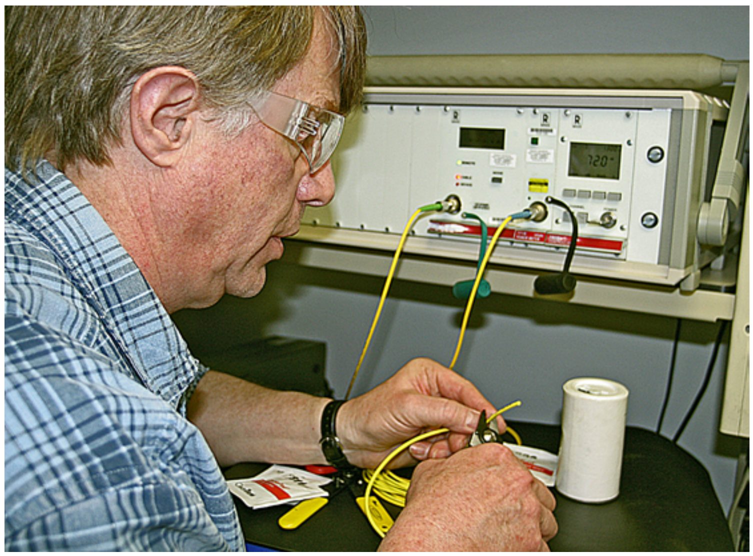
- Safety glasses for eye protection.
  - Working with fibers.
  - Illumination option.
  - Various styles.
  - Goggles.
  - Side shields.

- Laser eyewear.
  - Reduces or completely blocks any transmitted radiation to below the MPE level.
  - Rated for optical density (OD).
    - Base-10 logarithm of the attenuation factor by which the optical filter reduces beam power.
  - Three key elements.
    - Optical power level.
    - Viewing conditions.
    - Wavelength.
  - Wavelength and OD must be labeled.

OD	Attenuation	Transmission
1	10	0.1
2	100	0.01
3	1,000	0.001
4	10,000	0.0001
5	100,000	0.00001
6	1,000,000	0.000001

Working with Optical Fibers

During the process of testing, splicing and connectorizing fibers, a great quantity of work is done with optical fibers. Proper handling and disposal of these strands is important! Prevention is the best posture to use when working with or around optical fiber. Fiber can penetrate the skin and become irritating. You may also find that you cannot locate the imbedded fiber because of its clarity. The best method for removal is the use of Teflon™-tipped safety tweezers.



Prevention

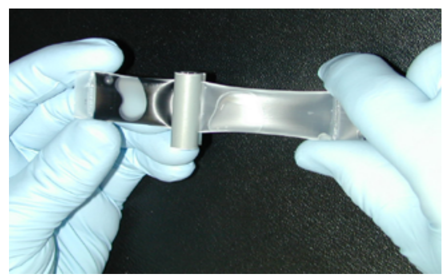
1. Use a dark chemical resistant work mat, table or workbench when working with optical fibers. The dark surface makes it easier to contrast glass fibers and chips. New portable cable tables are available that are specifically designed for fiber optic technicians and splicers.
2. The wearing of safety glasses is a good idea should any glass chips break off during the scribing process, especially during splicing and connectorization disciplines. For those working in laboratories, manufacturing or with high-power lasers, specific types of optical eye wear are available for protection from specific wavelengths.
3. The potential for ingestion. Do not eat or drink at or near the work area. Dropping fiber strands on a work surface may just be the place where your partner sets their donut and coffee down. When the donut is picked up, a "silica sandwich" has been digested.
4. Safely dispose of your fiber debris. Putting into garbage cans may cause accidental injury to cleaning staff. Do not throw fiber debris into raised computer or vault floors. These are pressurized and could cause accidental eye injury to workers lifting floor tiles. Proper disposal and handling are the best working methods. Place the chips in small plastic bottles, or wrap a piece of tape around itself with the strands placed on the inside and safely dispose of them in a sealed plastic bag.
5. Good lighting and visibility are critical.
6. Wash your hands after working with optical fibers. Never rub your eyes without washing first.
7. Always clean up your work area. This way the work environment will be safe for everyone.

Personal Protective Equipment

Clothing

- Clothing for manufacturing.
  - Lab coats and aprons.
  - Shoe covers.
  - Face masks, hairnets, and caps.
  - Gloves.
- Clothing for installation.
  - Boots.
  - Hardhats.
  - Gloves for fiber and cable handling.
- Breathing apparatus.
  - Respirators selected for specific particulates and coverage.

Safety Gloves



- When working with chemicals:
  - Material must be compatible with chemicals used.
  - Some people have latex allergies.
  - Nitrile recommended due to puncture and chemical resistance.
- When prepping cables:
  - Puncture resistance for strength members and armor.
- When working with optical fibers:
  - Options on colors, thickness, comfort, and allergies.
    - Darker colors recommended for best contrast against fibers and debris.
  - Disposable.
  - Must have tactile sensitivity due to small size of fibers.
  - Textured surface on fingers for holding fibers.
- Materials.
  - Nitrile – Recommended. Best puncture and chemical resistance. Available in different colors.
  - Chloroprene – Better moderate puncture and chemical resistance than latex.
  - Latex – Superior elasticity and tensile strength. May cause allergic reaction.
  - Vinyl – Should not be used with chemicals.

Chemicals

A variety of chemicals are commonly used in the manufacturing and installation of fiber, cable, connectors and splices. Each chemical requires a safety data sheet (SDS) to be supplied by the manufacturer or supplier.

Products that Require SDS

1. **Isopropyl alcohol**.
   Used for cleaning of optical end faces and connectors. Disposable towelettes (e.g., optic pads or alcohol-saturated pads) are sometimes easier as they are available in small disposable packages.

2. **Epoxies/anaerobic adhesives**.
   Used in the connectorization process. Be aware of the date codes on the packages for product expiration.

3. **Gel removers and cable gels**.
   Used in installations and inside cables. If a technician's hands, arms, etc., are exposed to the various chemicals in these solutions, thoroughly wash the affected areas.

4. **Cable lubricants**.
   Used to reduce friction in cable installations in ducted systems. Spills create the potential for falls and injury. Should a spill take place, the location should be barricaded until it is cleaned up. A temporary measure could be pouring sand or dirt on the spill until proper cleanup can take place.

Uncommon Stripping Agents

Early fibers used different coating materials instead of the acrylate coatings used today. In many cases, the coating had to be dissolved chemically because it couldn't be mechanically stripped. If some of this old fiber is encountered it may require chemical stripping.

1. **Methylene chloride**.
   This chemical is now rarely used in fiber optics because coating technologies improved allowing mechanical stripping. The applications involving methylene chloride are when buffer coatings must be removed from the fiber prior to splicing or connectorization.

2. **Acetone**.
   Used to clean off light buffer coatings. Best to use after mechanical or chemical (methylene chloride) stripping to assure a clean fiber surface. If acetone is hard to locate, use fingernail polish remover (90% acetone based).

Safety Data Sheets (SDS)

In 1985, the Occupational Safety and Health Administration (OSHA) of the Department of Labor issued standards for chemical manufacturers, importers, and distributors. OSHA identifies a hazardous chemical as one that has a physical and/or health hazard. Concerns such as flammability, combustibility, vapor or irritability are addressed.

A document known as the safety data sheet (SDS) establishes uniform requirements to assure that hazards of all chemicals used by manufacturing employees in the United States are evaluated and that this hazard information is then transmitted to employers and employees. The SDS is a technical bulletin detailing information about the physical or health hazards of a chemical or mixture. SDS were known as material safety data sheets (MSDS) until 2012.

Another OSHA's safety regulation known as Standard 29 CFR Telecommunications 1910.268 set forth safety and health standards that apply to the work conditions, practices, means, methods, operations, installations, and processes performed at telecommunications centers and at telecommunications field installations.

Workplace Hazardous Material Information System (WHMIS) is implemented in Canada through coordinated federal, provincial, and territorial legislation. The Department of Health (Health Canada) administers the Hazardous Products Act, which includes suppliers' labelling and SDS requirements.

If a material contains 1% of an ingredient that is considered hazardous, the entire mixture is considered hazardous under the definitions. This same rule applies if the material contains only 0.1% of a material identified as a known or suspected carcinogen, whether human or animal.

Hazardous Materials Safety

All products should be labeled with information on the safe storage and handling of the chemical, as well as instructions in case of contact, swallowing, etc.

When using chemicals, a training program encompassing the following should be provided:

- Location of the SDS information.
- Handling concerns of each solution.
- Storage and disposal of these solutions.
- Procedures for personal protection (clothing, eye wear, practices, etc.).
- Proper clean-up procedures.
- Incompatibility issues.
- Reporting practices for supervisory personnel.

For Further Information

Visit OSHA's website
www.osha.gov

Visit Health Canada's website
www.hc-sc.gc.ca/hecs-sesc/index.htm

The Work Area

Before starting an installation involving placing, splicing or termination, the public and the workers must be provided with a safe environment. In many cases, local governments or company policies will establish the proper safety requirements. The following are a few areas to consider:

- Guarding and protecting work areas.
- Testing and ventilating confined spaces and avoiding exposure to possibly harmful substances. The ANSI Z117.1 standard establishes the minimum safety requirements to be followed when entering, exiting and working in confined space operations. The standard includes definitions, identification, evaluation, atmospheric testing, isolation and decontamination, lockout and tagout, personal protection equipment, safeguarding, warning sign requirements, confined space permits, non permit requirements, and emergency response and rescue plans.
- Precautions pertaining to smoking or the use of open flames.
- Removing and replacing manhole covers.
- Wearing of appropriate safety equipment and clothing.
- Ladders.
- High voltage. When working near energized power lines, be aware of the safety hazards posed by induction and flashover. Be careful to remain outside the minimum approach distances as outlined in national electric safety codes.
- Personal protective equipment (PPE), clothing, and eye wear.

- The indoor work area.
  - Ventilation.
    - Location.
    - Air pressure.
  - Flooring should be smooth with no seams.
    - No carpeting.
  - If above raised flooring, the system must be turned off prior to opening tiles.
  - Possible eye damage from fiber chips.
  - No fabric on chairs and stools.
  - Safety signage.
    - Fiber debris.
    - No food or drink.
    - Laser signs, if used.
    - SDS location.
  - Safety clothing.
- The outdoor work area.
  - Work area should be safe, clean, and organized.
  - Good lighting.
  - No food or drink
  - Dark work surface.
    - Chemical resistant.
    - Nonreflective.
  - Personal protective equipment.
- Safe cable handling.
  - Sharp tools.
  - Cutting techniques.
  - Work clothes and gloves.
  - Sealing cable ends.
  - Proper disposal of debris.
  - Work table.

Installation Practices

Use the standard safety practices and awareness that your job skills require and show concern for those who do not have knowledge of the potential hazards. Work with your safety officer regarding any questions or concerns you may have.

1. **Tools**.

   Scissors, cutters, tweezers and cleaving tools can all have sharp points and edges. Careful handling of these instruments and proper storage should minimize any potential hazards.

2. **Pulling lubricants**.

   Lubricants used for fiber optic installations can be extremely slippery. Spills should be cleaned up immediately to prevent falls.

3. **Mechanical tools**.

   During cable installations, cables are installed using capstans, winches and other devices. These devices are all moving and may have a great amount of tension being applied to the pulling eye and/or swivel, and can be a potential hazard to personnel working with them. Follow all safety procedures by the manufacturer and your own company's safety guidelines.

4. **Fusion splicing**.

   Fusion splicing machines involve the use of an electrode arc for fusing the optical fibers together. In highly-electrified areas such as vaults, this arc could cause an explosion.

5. **Cable placement**.

   Hazards for cable placement include heavy equipment, cable pulling tension, ladder safety, proximity to high voltage, trench cave-ins, and confined spaces.

6. **Cable stripping**.

   Concerns when stripping cable include tools, tool forces, and metallic cable elements.

7. **Safety standards**.

   Always follow installation safety standards. In North America, follow the National Electrical Safety Code. Outside of North America, follow your local guidelines.

8. **Aerial installations**.

   When performing an aerial installation, consult IEEE-524 for information on high voltage safety. Ladder and bucket trucks should have regular inspections and fall protection. Weight limits and proper positioning should also be keep in mind.

9. **Direct buried installations**.

   When performing a direct buried installation, be sure meet shoring requirements during trenching and/or excavation. Call to locate any underground utilities.

10. **Ducted installations**.

    Take care with cables under tension.

Cable Installation Safety Issues

When placing aerial or underground fiber optic cable, crew safety is of utmost importance. All precautions and safety requirements of the respective company must be followed. When required, warning signs and cones must clearly define the work area in order to safely channel traffic. On streets and highways, always place the cable in the same direction as the flow of traffic and place flagmen to direct traffic.

As stated in NESC Section 42, all crew members should have the appropriate tools and personal protective equipment to properly perform the job. Installation of the cable without the proper equipment may put personnel and the cable at risk.

When placing ADSS or OPGW on active structures, or structures involving power crossings, observe the safety precautions outlined in the company's applicable procedures. When pulling up and tensioning self-supporting cable, observe the same precautions used when pulling up and tensioning metallic phase conductors or any other aerial cables. When aerial lift equipment is used to place self-supporting cable, all precautions and instructions outlined for placement of phase conductors must be observed.

Although ADSS is an all-dielectric cable, some conductivity can result from moisture on the cable and in the surrounding air. As a precaution in high voltage environments, it is recommended that the installed cable and metallic attachment hardware are grounded prior to touching. For cables installed in other situations, the NESC should be consulted for recommendations. The cable can be classified as either a fiber optic supply or fiber optic communications cable, and should meet the requirements for an effectively grounded neutral as defined in NESC Rule 230E1. The precautions in the following paragraphs must be observed to ensure safety during and after the cable installation.

In high voltage transmission applications, leakage current can be induced onto ADSS and attachment hardware even when the cable is a relatively long distance from the phase conductors. ADSS manufacturers can calculate the leakage current based upon the cable position relative to the phase conductors and to the ground, the transmission voltage, and the surface resistivity of the cable jacket. The cable surface resistivity is dependent on the moisture and contaminants on the cable. A clean, dry cable has a surface resistance of ~10 MΩ/meter and a dirty, wet cable has a surface resistance of ~4-6 MΩ/meter. Do not install cables on active high voltage transmission towers during wet environmental conditions.

OPGW cable is a metallic conductor. Thus the same safety rules associated with stringing power conductor are applicable. Safe approach to active conductors and the potential for flashover to the OPGW must be considered and the appropriate work rules applied. Specific safe approach distance to active phase conductors are defined in the NESC work rules sections 43 and 44. The safe approach distance is different for electrical personnel and telecommunications personnel. The values listed should be the minimum safe approach distance to active phase conductors.

For all cable installation, underground or aerial, working tensions of the cable pulling and the cable tensions of the cable sag process must consider the safe working load of the associated equipment and tools. Safety margins of a minimum of 50% should be considered. Grounding and protection of personnel of the installation apparatus is a must. Adequate electrical protection must be established at all work sites. The method required and the equipment used will be determined by the degree of exposure to electrical hazards and the soil conditions at the site. All metallic equipment, hardware, anchors, and structures within such work sites must be common bonded together, and then grounded to ensure worker safety.

Aerial Safety Issues

Crew safety is of the utmost important when placing fiber optic cable. When placing aerial cable, all precautions and safety requirements of the respective company shall be followed. When required, use of warning signs and traffic warning cones shall clearly define the work area to safety channel the traffic. On streets and highways, always place the cable in the same direction as the traffic flow and use flagmen to control traffic.

All crew members should have the appropriate tools and personal protective equipment to properly perform the job. Installation of the cable without the proper equipment may place personnel and the cable at risk.

When placing aerial cable on active structures, or structures involving power crossings, observe the safety precautions outlined in your company's applicable procedures. When pulling up and tensioning self-supporting cable, observe the same precautions used when pulling up and tensioning any other aerial cables. When aerial lift equipment is used for placing self-supporting cable, all precautions for placing phase conductors, as well as the instructions covering the equipment must be observed.

Although aerial cable is all-dielectric, some conductivity can result from moisture on the cable and in the surrounding air. As a precaution in high voltage environments, it is recommended that the installed cable and metallic attachment hardware are grounded prior to touching. For cables installed in other situations, the National Electric Safety Code (NESC) should be consulted for recommendations. The cable can be classified as either a "fiber optic supply" or "fiber optic communications" cable, and meets the requirements for an effectively grounded neutral as defined in NESC rule 230E1. The precautions in the following paragraphs must be observed to assure safety during and after the cable installation.

Leakage current can be induced onto aerial cable and attachment hardware even when the cable is a relatively long distance from the phase conductors. Manufacturers can calculate the leakage current based upon the cable position relative to the phase conductors and to the ground, the transmission voltage and the surface resistance of the cable jacket. The cable surface resistance is dependent on the moisture and contaminants on the cable. Since a clean, dry cable has a surface resistance of 10^{14} Ω/ft and a dirty, wet cable has a surface resistance of 10^{6} Ω/ft. **Do not install cables on active towers during wet environmental conditions.**

When the cable is too close to the phase conductors, a scintillation can occur through the air from phase conductors to the cable. This scintillation from a phase conductor to ADSS cable can occur only when the resistance of the cable sheath to the grounding location is low enough to lower the induced voltage. In the worse case condition, the cable resistance is zero, at which time it will be similar to a grounded metal rod. A grounded rod configured in air has a flashover voltage of 15 kV/in for large gaps. Hence, the safe approach distance to keep the phase conductors away from the ADSS cable can be calculated by:

$$SD = E/15$$

where SD = distance (inches), and E is the phase-to-ground voltage (kV).

Note: The work rules of the NESC section 43 and 44 should be used to determine safe approach to live systems.

Specific safe approach distance to active phase conductors are defined in the NESC work rules sections. The safe approach distance is different for electrical personnel and telecommunications personnel. The values listed should be the minimum safe approach distance to active phase conductors.

Aerial Safety Issues

(Continued)

Wet/Rainy Weather Conditions

When splicing ADSS cable during wet or rainy conditions near active high voltage phase conductors, it is advised to ground the cable between the work area and the spans (such as at the attachment hardware). This will prevent dangerous leakage currents and transients from flowing through personnel. In dry weather, there is little induced charge on the cable; however as a personnel safety practice, the cable should be grounded between the work area and the spans.

When the cable is wet, the resistance to ground is low near the tower or grounded structure, so there is little voltage potential on the metal grips or cable at these points. However, at distances of 10 or 15 feet or further from the metal grips, a voltage potential may exist. To avoid dangerous electrical hazards, **ground the cable within 3 to 5 feet on both sides of the area to be touched**.

Dry Weather Conditions

When the cable is suspended by insulators or on wooden poles, a voltage potential may be induced in the metal suspension grips and support hardware. To avoid dangerous electrical shock, **ground the metal grips before touching**. The cable can be touched anywhere when it is dry, because there is little charge induced on the small area that is touched.

Scintillation

Careful selection of the suspension position of the ADSS cable prevents dangerous scintillation. Scintillation is a surface arc that may pose a cable and personnel hazard. These scintillations occur mainly at the attachment points of the cable; therefore, minimum clearance between the cable and phase conductors should be determined at this point. The separation and clearance requirements for ADSS cable is found in the NESC section 230.

The recommended position must be such that there will be no contact between the ADSS cable and the phase conductors or static wires, either during installation or under maximum environmental load conditions. If during a rare case of galloping conductors contact should occur, there may be a potential for scintillation. However, the potential for subsequent cable damage is minimal.

Adequate electrical protection must be established at all work sites. The method required, and the equipment used, will be determined by the degree of exposure to electrical hazards and the soil conditions at the site. All metallic equipment, hardware, anchors and structures within such work sites must be common bonded together, and then grounded to assure worker safety.

Review Questions

1. Which laser classification designates a retina-safe laser?

2. What typically defines a Class II laser?

3. At low power levels, are shorter wavelengths or longer wavelengths more dangerous?

4. Are there laser safety glasses available that offer protection against Class III or Class IV lasers?

5. What safety forms must be available for review when working with chemicals in the workplace?

6. What is the best way to dispose of exposed fiber shards, scraps, or debris?

7. What must always be verified before inspecting a connector endface with a direct magnification inspection scope?

8. Why is working with fiber optics on a dark work surface important?

9. Is there a potential for eye damage when viewing a Class 1M source with a fiber inspection scope?

10. Which device is recommended for viewing an optical connector if this system cannot be determined to be carrying power or not?

Appendix A

Worksheets

MatriX Engineering

Fiber Selection

Single-mode Fiber

Qty	Type
	ITU-T G.652 SMF (OS1)
	ITU-T G.652D LWP SMF (OS2)
	ITU-T G.655 NZDS
	ITU-T G.657 bend-insensitive

Operating wavelength

- ☐ 1310 nm
- ☐ 1490 nm (FTTx)
- ☐ 1550 nm
- ☐ 1310/1550 nm
- ☐ 1625 nm

Attenuation

__________________ dB/km @ 1310 nm

__________________ dB/km @ 1490 nm

__________________ dB/km @ 1550 nm

__________________ dB/km @ 1625 nm

Single-mode dispersion

________________ps/nm-km @ 1310 nm

________________ps/nm-km @ 1490 nm

________________ps/nm-km @ 1550 nm

________________ps/nm-km @ 1625 nm

Zero dispersion

_________________nm ± _________ nm

Cutoff wavelength (cabled)

_________________nm ± _________ nm

Multimode Fiber

Qty	Type
	62.5 µm OM1 (legacy)
	50 µm OM2 (legacy)
	50 µm OM3 (laser-optimized)
	50 µm OM4 (laser-optimized)
	50 µm OM5 (wide band)

Operating wavelength

- ☐ 850 nm
- ☐ 1300 nm
- ☐ 850/1300 nm

Attenuation

__________________ dB/km @ 850 nm

__________________ dB/km @ 1300 nm

Multimode bandwidth

	@ 850 nm	@ 1300 nm
Source type	☐ LED ☐ VCSEL ☐ FP laser	☐ LED ☐ VCSEL ☐ FP laser
Max distance* (in meters)		
Bandwidth** (in MHz-km)		

*Max distance dependant upon source.
**May be stated as “IEEE 802.3z compliant”.

Cabling Options

Cable Types

Loose tube	______	➡	Buffer tube	_____________	mm
Unitube	______				
Stranded	______				
Single jacket	______				
Dual jacket	______				
Armored	______				
Gel filled	______				
Unfilled	______				
Powder	______				
Tape	______				
Dielectric central member	______				
Steel central member	______				
OFNR/OFNP	______				
Indoor/outdoor rated	______				
Tight buffered	______				
Distribution	______	➡	Buffer size	_____________	µm
Distribution w/sub-units	______				
Breakout	______	➡	Sub-unit	_____________	mm
Hybrid/composite cable	______	➡	Copper pairs	_____________	gauge
Specialty cable	______				

Cable Jackets

PE – Polyethylene	______	PU – Polyurethane	______
PVC – Polyvinylchloride	______	FCP – Fluorocopolymer	______
T – Teflon™	______	U.L. Listing/NEC/CEC	______
K – Aramid yarn (Kevlar™)	______	Other (specify)	______

Sequential Markings

Metric	_____________
Footage	_____________
Ripcords	_____________

Mechanical Specifications

Minimum bend radius, installation	_____________	in/cm
Minimum bend radius, long-term	_____________	in/cm
Maximum tensile load, installation	_____________	lbs.
Maximum tensile load, long-term	_____________	lbs.
Crush resistance	_____________	lb/inch ________N/cm
Cable reel length(s)	_____________	
Number of cable reels	_____________	
Cable reel weights	_____________	

Cable Management Products

Panels

Fiber count ______________ ☐ MM ☐ SM

Distribution panel ______________ Splice tray ______________ Connector type/polish ______________

Splice panel ______________ Splice tray ______________

Patch panel ______________ Connector type/polish ______________

Premises panel ______________ Connector type/polish ______________

Mounting ☐ 19” ☐ 23” ☐ Wall ☐ Rack ☐ Cabinet ☐ Shelf required

Rack units ______________

Splice Closures

Fiber count _____________ Cable ports ______________

Burial splice closure _____________ Aerial splice closure ______________

Splice closure type

In-line _____________

Butt _____________

Mid-entry ports _____________

Slack tray _____________

Splice tray

Heat shrink ______________

Ribbon ______________

Mechanical ______________

Vault

Slack _________ Amount ____________ Mid-entry ports ______________

Bonding to ground requirement ____

Pedestals

Fiber count _____________ Mid-entry ______________

Splice tray _____________ Connectors ______________

Slack _____________ Amount ______________

Fiber Distribution Hub

Fiber count _____________ Mid-entry ______________

Connector type _____________ Polish ______________

Vault _____________ Pigtail length ______________

Incoming fibers _____________ Outgoing fibers ______________

Test Equipment Selection

Fiber type	Wavelength
☐ Single-mode	☐ 1310 nm ☐ 1550 nm ☐ 1490 nm ☐ 1577 nm ☐ 1625 nm
☐ Multimode	☐ 850 nm ☐ 1300 nm

Fiber connector	
Type	
Polish	

OTDR testing

OTDR	OTDR type ☐ Full feature ☐ Mini ☐ Fiber break locator
Wavelengths	Dynamic range
Pulsewidth	Resolution
Terminator	Terminator type and polish
Deadzone boxes (DZB)	DZB connector type
DZB fiber type	DZB connector polish

Optical loss testing

Power meter	Power meter type ☐ Standard ☐ High-power (CATV) ☐ DWDM ☐ PON
Wavelengths	Resolution ☐ 0.1 dB ☐ 0.01 dB
dB/dBm	dBm
Light source	Light source type
Wavelengths	Connector type and polish
Optical loss test set (incl. power meter and light source)	OLTS type

Other testing

Microscope	
Magnification	Adapters
Digital inspection scope	
Resolution	Adapters
Visible laser (670 nm)	Visible laser type ☐ Class II ☐ Class IIIA ☐
Fiber identifier	Fiber identifier type ☐ 250 µm ☐ 900 µm ☐ Ribbon
Variable optical attenuator (VOA)	
VOA range	VOA connector type and polish
Talk set	Talk set dynamic range

Placement Technique

Underground

Trench ______________

Encased ______________

Duct ______________

Innerduct ______________

Maxcell ______________

Direct buried ______________

PlowCon ______________

Boring ______________

Duct ______________

Innerduct ______________

Maxcell ______________

Aerial

Lashed ______________

Self-supporting ______________

Aerial duct ______________

Premises

Cable tray ______________

Flexduct ______________

Raceway ______________

Plenum ______________

Riser/chaser ______________

Fiber Installation Inspection Report

System name	Project #
Span description	Inspection date
Contractor Name	Contractor Phone
Contractor Address	
Status	Completion date

Reference specifications (Note: In progress inspection required for some items)

Cable Handling & Install	Pass	Fail	N/A	Panel Locations	Pass	Fail	N/A
On-reel verification report	☐	☐	☐	Type, specification, general quality	☐	☐	☐
Pre-install mark and notification	☐	☐	☐	Visual inspection, properly installed	☐	☐	☐
Bend radius	☐	☐	☐	Connector insertion loss	☐	☐	☐
Cable ends sealed	☐	☐	☐	Cable breakout color coded	☐	☐	☐
Protection, support, environment	☐	☐	☐	Termination into panel per specifications	☐	☐	☐
Cable labeling	☐	☐	☐	Termination installed per specifications	☐	☐	☐
Sufficient sheath slack	☐	☐	☐	Pigtail length, place, radius	☐	☐	☐
Proper cable tension and spooling	☐	☐	☐	Bldg. entrance insulating splice	☐	☐	☐
Aerial install techniques	☐	☐	☐	Bldg. entrance cored, sealed	☐	☐	☐
Buried install techniques	☐	☐	☐	Buffers labeled	☐	☐	☐
Duct install techniques	☐	☐	☐	Duct install techniques	☐	☐	☐
Proper cable support (Kellems grips, strain relief)	☐	☐	☐	Proper cable support (Kellems grips, strain relief)	☐	☐	☐
Splice Location	Pass	Fail	N/A	**Miscellaneous**	Pass	Fail	N/A
Type	☐	☐	☐	Route markers and signs (OSP)	☐	☐	☐
Specification	☐	☐	☐	Permits posted	☐	☐	☐
Placement	☐	☐	☐	Backfill, compaction, settling	☐	☐	☐
Closures	☐	☐	☐	Asphalt/concrete restoration	☐	☐	☐
Splice fiber storage	☐	☐	☐	Landscape restoration	☐	☐	☐
Slack amount	☐	☐	☐	Other restoration	☐	☐	☐
Splice grounding	☐	☐	☐	Pedestal, handhole, place protection (OSP)	☐	☐	☐
Fiber/cable I.D. tagging	☐	☐	☐	Excavation and general safety (OSP)	☐	☐	☐
Loss optimization	☐	☐	☐	Clean-up housekeeping	☐	☐	☐
Microbends/macrobends	☐	☐	☐	Documentation as-builds	☐	☐	☐
Pinched buffer tubes	☐	☐	☐	Testing compliance	☐	☐	☐
Proper cable support (Kellems grips, strain relief)	☐	☐	☐	Other requirements	☐	☐	☐
Grounding and Bonding	Pass	Fail	N/A	Remarks on Unsatisfactory or Unacceptable Conditions			
Connection leads	☐	☐	☐				
Splice point grounds	☐	☐	☐				
Shield bond connection	☐	☐	☐				
Cable entry grounding closure	☐	☐	☐				
Mid-span external grounding	☐	☐	☐				
Isolation: other plant, utilities (OSP)	☐	☐	☐				
Contractor				Inspector			

OTDR Acceptance Test Form

The OTDR acceptance test form should be used when performing acceptance tests on incoming optical cables to compare the values (length, loss, structure) against those specified when purchased. It is recommended that all optical fibers be tested upon receipt of the cable especially if physical damage is apparent on the reel or pallet, and that the test occurs with a copy of the engineering and purchasing documents to check each item required.

Key requirements of the acceptance test form are: name of the fiber manufacturer, name of the cable manufacturer, sequential markings (metric or footage), length, and dB/km at the wavelength tested. Physical elements that the OTDR cannot monitor include: physical condition of the cable (damage, packing, etc.); actual fiber count; internal cable structure (tubes, fibers, color codes); and markings.

This document should be accompanied by OTDR traces or waveforms, either stored or printed out for you or your client's records. Look for linear traces and lower dB/km loss values at longer wavelengths, e.g., 1550 nm versus 1310 nm. If the loss is higher at a longer wavelength, macrobending or microbending is the cause.

Customer	Work Order
Fiber	Cable Mfr.
IOR	Physical Appearance
Reading From	Cable Reel #
Sequential Marking Start #	Sequential Marking End #

Fiber ID	Distance (m/feet)	dB/km @ 850 nm	dB/km @ 1300/1310 nm	dB/km @ 1550 nm	dB/km @ 1625 nm
Blue					
Orange					
Green					
Brown					
Slate					
White					
Red					
Black					
Yellow					
Violet					
Rose					
Aqua					

Comments		
Operator	Date	Form of

Splice Loss Record

Customer		Job Number
Fiber	IOR	Operator
Manufacturer		Date
Reading From		Wavelength

Subgroup Color		Splice 1 Loss (dB)	Splice 2 Loss (dB)	Splice 3 Loss (dB)
Blue buffer tube	1 Blue			
	2 Orange			
	3 Green			
	4 Brown			
	5 Slate			
	6 White			
	7 Red			
	8 Black			
	9 Yellow			
	10 Violet			
	11 Rose			
	12 Aqua			
Orange buffer tube	1 Blue			
	2 Orange			
	3 Green			
	4 Brown			
	5 Slate			
	6 White			
	7 Red			
	8 Black			
	9 Yellow			
	10 Violet			
	11 Rose			
	12 Aqua			
Distance				
Sequential pre				
Sequential post				

Splicing documentation is recorded by the OTDR operator. For long spans, increased OTDR averaging may be required to obtain optimum measurements. If the splice meets the specified value, record the dB level. If loss exceeds specifications, each resplice should be documented.

To update actual cable lengths, the sequential cable markings should be identified and charted. Remember the OTDR measures fiber length and not cable length! The OTDR can be adjusted to actual cable index of refraction (CIR) versus the fiber index of refraction (FIR) for more accurate location.

Appendix B

Miscellaneous

MatriXEngineering

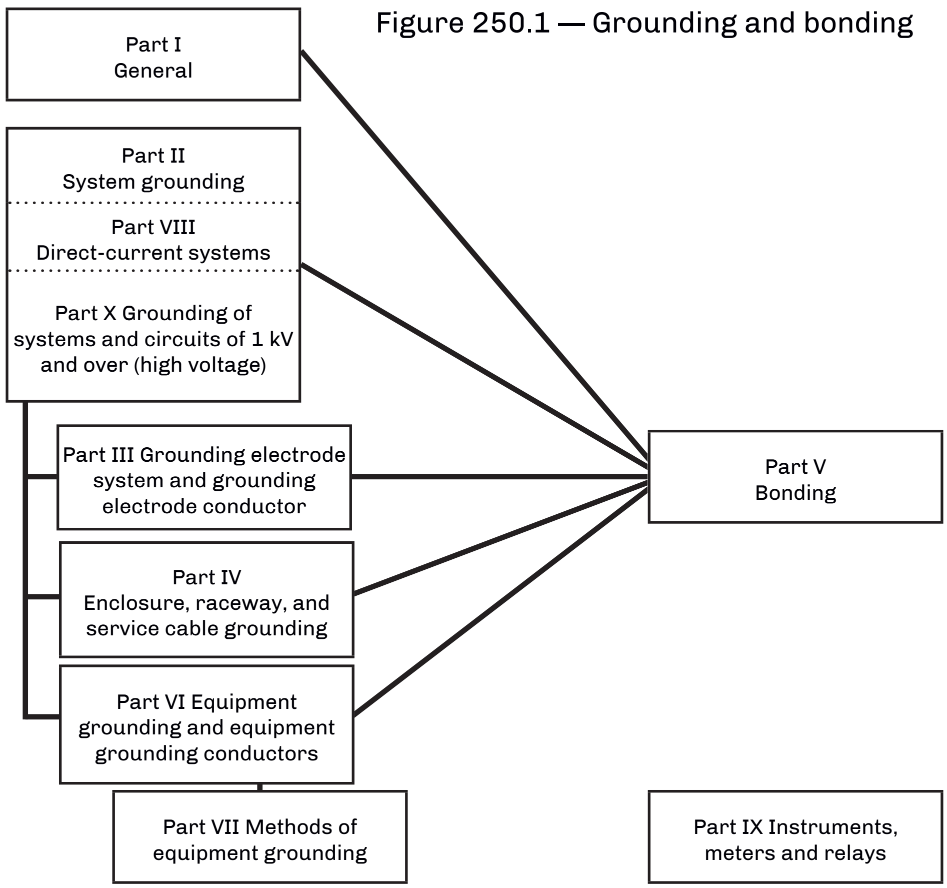
National Electrical Code Handbook

Article 250 – Grounding and Bonding

250.1 Scope. This article covers general requirements for grounding and bonding of electrical installations, and the specific requirements in (1) through (6).

(1) Systems, circuits, and equipment required, permitted, or not permitted to be grounded.
(2) Circuit conductor to be grounded on grounded systems.
(3) Location of grounding connections.
(4) Types and sizes of grounding and bonding conductors and electrodes.
(5) Methods of grounding and bonding.
(6) Conditions under which guards, isolation or insulation may be substituted for grounding.

Figure 250.1 — Grounding and bonding



250.3 Additional grounding and bonding requirements.

Communication circuits	Article 800
CATV and radio distribution systems	Sections 820.93, 820.100, and 820.103
Health care facilities	Article 517
Information technology equipment	Section 645.15
Radio and television equipment	Section 810
Switchboards and panelboards	Section 408.3(D)

250.80 Service raceways and enclosures.

250.96 Bonding other enclosures.

National Electrical Code Handbook

Article 770 – Optical Fiber Cables and Raceways

770.1 Scope.

770.3 Locations and other articles.
- a. Spread of fire or products of combustion.
- b. Ducts, plenums, and other air-handling spaces.

770.4 Optical fiber cables.

770.5 Types.
- a. Nonconductive.
- b. Conductive.
- c. Composite.

770.6 Raceways for optical fiber cables.

770.7 Access to electrical equipment behind panels designed to allow access.

770.8 Mechanical execution of work.

770.49 Fire resistance of optical fiber cables.

770.50 Listings, marking, and installation of optical fiber cables.

770.51 Listing requirements for optical cables and raceways.
- (A) Types OFNP and OFCP.
- (B) Types OFNR and OFCR.
- (C) Types OFNG and OFCG.
- (D) Types OFN and OFC.
- (E) Plenum optical fiber raceway.
- (F) Riser optical fiber raceway.

770.52 Installation of optical fiber and electrical conductors.
- (A) With conductors for electric light, power, Class 1 circuits.
- (B) With other conductors.
- (C) Grounding.

770.53 Applications of listed optical fiber cables and raceways.
- (A) Plenum.
- (B) Riser.
- (C) Other wiring within buildings.
- (D) Hazardous (classified locations).
- (E) Cable trays.

Canadian Electrical Code

Section 56 – Optical Fiber Cables

56-000 Scope. This Section applies to the installation of optical fiber cables in conjunction with electrical systems and is supplementary to, or amendatory of, the general requirements of this Code.

General

56-100 Special terminology.

56-102 Types.
(A) Nonconductive cables.
(B) Conductive cables.
(C) Hybrid cables.

56-104 Approvals.

56-106 Acceptance of Inspector.

Installation Methods

56-200 Nonconductive optical fiber cables.

56-202 Conductive optical fiber cables.

56-204 Hybrid cables.

56-206 Penetration of a fire separation.

56-208 Optical fiber cables in a vertical shaft.

56-210 Optical fiber cables in ducts and plenum chambers.

56-212 Raceways.

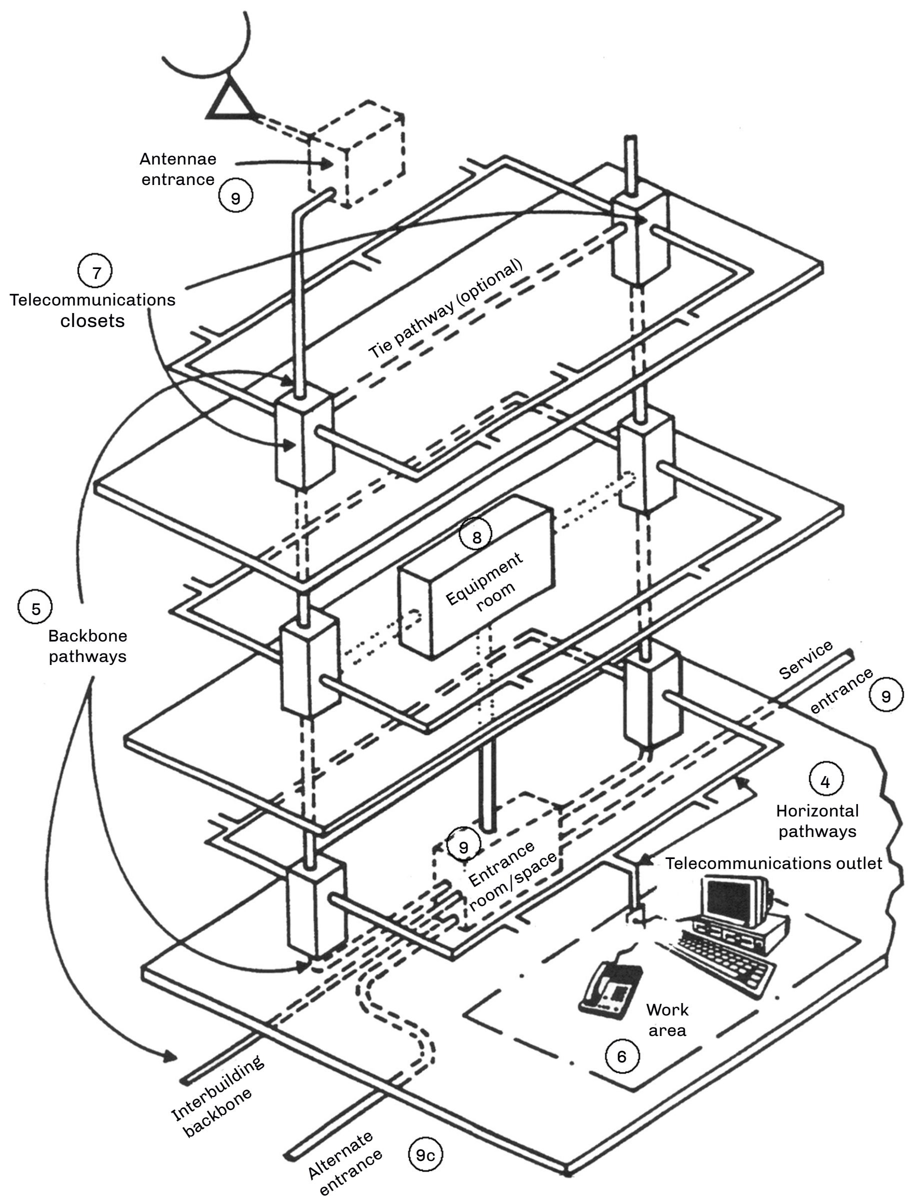
56-214 Grounding of entrance cables.

TIA-569

Commercial Building Standard for Telecommunications Pathways and Spaces

The TIA-569 standard encompasses the telecommunications considerations both within and between buildings. This includes the pathways, spaces and areas associated with the fiber optic media and terminal equipment. The equipment can include voice, video, data, audio, security, environmental controls, alarms, and paging systems. The numbers are keyed to match the TIA-569 chapters and corresponding diagram.

4. Horizontal pathways and related spaces.
5. Backbone pathways.
6. Work station.
7. Telecommunications.
8. Equipment room.
9. Entrance facilities.



The TIA-569's international equivalent is IEC 14763. The Canadian equivalent, CAN/CSA-T530, was withdrawn by the CSA in favor of TIA-569.

TIA-569
(Continued)

Horizontal Pathways and Spaces

4.1 General.

Horizontal pathways are facilities for the installation of telecommunications cable from the telecommunications closet to the work area telecommunications outlet/connector. Horizontal pathways encompass underfloor, access floor, conduit, tray and wireway, ceiling, and perimeter facilities.

4.2 Underfloor pathways.

4.2.1 Underfloor duct.
4.2.2 Cellular floor.

4.3 Access floor.

4.3.1 General.
4.3.2 Design guidelines.
4.3.3 Installation.
4.3.4 Outlet boxes.
4.3.5 Pull boxes.

4.4 Conduit.

4.4.1 General.
4.4.2 Design guidelines.
4.4.3 Installation.
4.4.4 Outlet boxes.
4.4.5 Pull boxes.

4.5 Cable trays and wireways.

4.5.1 General.
4.5.2 Location.
4.5.3 General horizontal design information.
4.5.4 Support.
4.5.5 Accessories.
4.5.6 Installation.

4.6 Ceiling pathway.

4.6.1 Ceiling pathway/space.
4.6.2 Design guidelines.
4.6.3 Telecommunications closet termination.
4.6.4 Wall and partition cabling.
4.6.5 Cable support.

4.7 Perimeter pathways.

4.7.1 General.
4.7.2 Types.
4.7.3 Design guidelines and procedures.

4.8 Miscellaneous.

4.8.1 Undercarpet.
4.8.2 Consolidation points.
4.8.3 Multi-user telecommunications outlet assemblies.
4.8.4 Interstud.
4.8.5 Overfloor raceway.
4.8.6 Exposed cabling.
4.8.7 Poke-thru.
4.8.8 Curtain wall.

TIA-569

(Continued)

Intrabuilding Backbone Pathways and Related Spaces

5.1 General.

5.2 Design guidelines.

- 5.2.1 General.
- 5.2.2 Pathway design guidelines.
- 5.2.3 Design guidelines for pull and splice boxes.

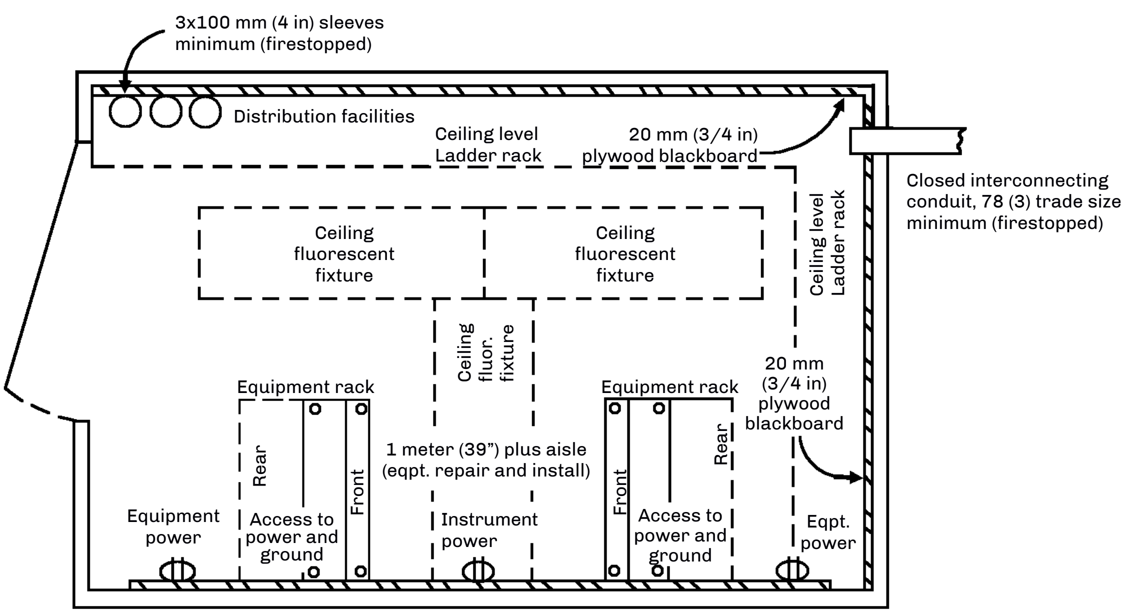
Work Areas

6.1 General.

6.2 Telecommunications outlet locations.

- 6.2.1 General.
- 6.2.2 Outlet density.
- 6.2.3 Outlet location considerations.

Telecommunications Closets



7.1 General.

- 7.1.1 The telecommunications closet.

7.2 Design considerations.

- 7.2.1 General.
- 7.2.2 Size and spacing.
- 7.2.3 Floor loading.
- 7.2.4 Provisioning.
- 7.2.5 Telecommunications closet penetrations.
- 7.2.6 Security and fire protection.
- 7.2.7 Environmental considerations.

TIA-569
(Continued)

Equipment Rooms

8.1 General.

8.2 Design guidelines.
- 8.2.1 Site selection.
- 8.2.2 Size.
- 8.2.3 Provisioning.

8.3 Main terminal space.
- 8.3.1 General.
- 8.3.2 Design consideration.
  - 8.3.2.1 Site selection.

Entrance Facilities

9.1 General.

9.2 Entrance location considerations.

9.3 Service entrance pathway.
- 9.3.1 General.
- 9.3.2 Entrance pathway methods.
  - 9.3.2.1 Underground.
  - 9.3.2.2 Direct buried.
  - 9.3.2.3 Aerial.
  - 9.3.2.4 Tunnels.

9.4 Entrance point.
- 9.4.1 General.
- 9.4.2 Conduit entrance design guidelines.

9.5 Entrance room or space.
- 9.5.1 General.
- 9.5.2 Location.
- 9.5.3 Design.

TIA-569
(Continued)

Annex A – Firestopping

A.1 Scope.

A.2 Terminology and definitions.

A.3 Firestops.

- A.3.1 Introduction.
- A.3.2 Fire-rated barriers.
- A.3.3 Penetrations.
- A.3.4 Evaluation of firestop systems.
- A.3.5 Qualification testing.
- A.3.6 Testing requirements for through-penetration firestops.
- A.3.7 Firestop ratings for through-penetration firestops.
- A.3.8 Guidelines for membrane-penetration firestops.
- A.3.9 Seismic consideration.
- A.3.10 Engineering judgments.

A.4 Quality control considerations.

A.5 Categories of firestop systems.

- A.5.1 Introduction.
- A.5.2 Mechanical systems.
- A.5.3 Nonmechanical systems.
  - A.5.3.1 Putty.
  - A.5.3.2 Caulk.
  - A.5.3.3 Cementitious (cement-like) materials.
  - A.5.3.4 Intumescent sheets.
  - A.5.3.5 Intumescent wrap strips.
  - A.5.3.6 Silicone foams.
  - A.5.3.7 Pre-manufactured pillows.

TIA-569

(Continued)

Annex C – Interbuilding Backbone Pathways and Related Spaces

C.1 General.

C.2 Building site and entrance considerations.

C.3 Interbuilding and entrance pathways.

C.4 General considerations for pathways types.

- C.4.1 Underground.
- C.4.2 Direct buried.
- C.4.3 Aerial.
- C.4.4 Tunnels.

C.5 Interbuilding pathway design considerations.

- C.5.1 Conduit.
- C.5.2 Cable tray and wireway.

C.6 Space design considerations.

- C.6.1 Maintenance holes.
- C.6.2 Handholes.
- C.6.3 Pull or splice box design.

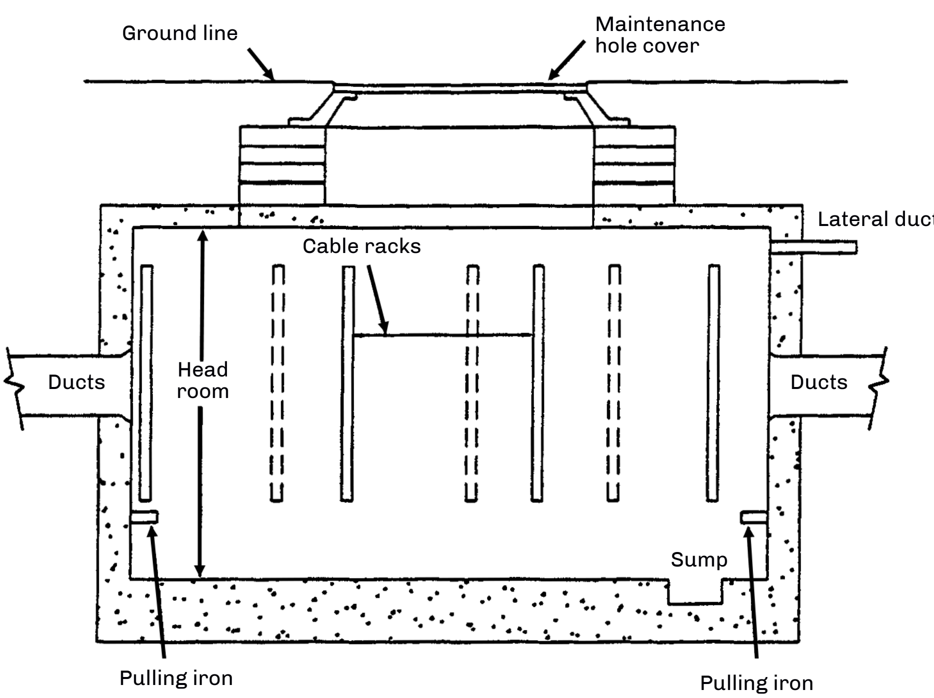


Figure C.6-1: Typical maintenance hold (type A).

Student Notes

Fiber Optic Glossary

MatrixEngineering

Glossary of Terms

µm
A micron; a millionth of a meter. Common unit of measurement of optical fibers.

Abrasion resistance
A cable's ability to resist surface wear.

Absorption
Caused by impurities introduced during the manufacturing process, absorption creates loss in a fiber by turning light energy into heat. The amount of absorption is determined by the wavelength and depends upon the composition of the glass or plastic. Absorption and scattering are the two causes of intrinsic attenuation in an optical fiber.

Acceptance angle
See *Critical angle*.

Acceptance test
A test to confirm that an optical cable or link meets established performance specifications.

Active device
An active device is a device that requires electrical power. One type is those that convert signals between electrical and optical formats such as lasers, LEDs, and photodiodes. Active devices also can manipulate light, such as optical amplifiers and modulators.

Active optical cable (AOC)
A fiber optic cable that has been preterminated with an external electrical endface, thereby removing the termination process. The electrical endfaces can be manufactured with most module formats. The most common module formats are the SFP and HDMI interfaces, but DVI, VGA, SFP+, and QSFP+ interfaces also can be provided.

Adapter
A mechanical device that transitions the transmitter or receiver of an optical loss test set (OLTS) to the fiber optic cable assembly.

Add/drop multiplexer (ADM)
A mid-span electronic element that provides optoelectric/electro-optic conversion to add, drop, or multiplex photonic signals.

Aeolian vibration
Wind-induced vibration, usually high frequency, which causes oscillation of cable.

Aerial
A type of installation in which the cable is connected to poles or towers by means of clamps or other attachment hardware.

Aerial cables
Cables that are designed to handle environmental concerns such as wind and ice loading, pollution, UV radiation, thermal cycling, stress, and aging in aerial placements. There are several variations of aerial cables including OPGW and ADSS.

Air blown fiber (ABF)
An installation technique developed by British Telecom where micro ducts or "pipe cables" are installed, and then optical fibers or fiber bundles are blown into the cable with spans reaching 10,000 feet.

Air handling plenum
A space within a building designed for the movement of environmental air, e.g., a space above a suspended ceiling or below an access floor.

Air polish
The first polish of a ferrule or termini after the fiber has been cleaved. The lapping film is passed over the connector endface in the air to polish the fiber stub just above the ferrule endface.

Alignment sleeve
An appliance for mating and holding two connector ferrules in alignment. Also known as a C-clip.

All-dielectric
No metal elements.

All-dielectric self-supporting (ADSS)
A loose tube cable structure without any metallic elements. Specified by the IEEE P-1222 standard, ADSS cable is designed for long spans up to 10,000 feet. Six variations are listed, based on the cable's outside diameter.

All-optical network (AON)
A network that uses only optical components to produce, direct, condition, control, and connect optical signals.

American National Standards Institute (ANSI)
The official American standards body through which standards are published and various other standards committees are accredited.

Anaerobic
In adhesives, a bonding method that uses its own chemical reaction to complete the adhesion.

Analog
A data format using continuous physical variables such as voltage amplitude (AM) or frequency (FM) variations that are analogous to the original signal.

Angled physical contact (APC)
A ferrule endface at 8° that minimizes Fresnel reflections when in contact with another APC termination. APC polishes normally have a component reflectance value of 60-70 dB. They are most often used in analog, DWDM, and FTTx installations.

Angular misalignment
The fiber optic cores of a mated pair of connectors are held at an angle, either by mispolish, worn alignment sleeve, or contamination.

Application-specific optical fiber (ASOF)
Fibers built for specific applications such as those doped with erbium for use in fiber amplifiers or the high numerical aperture fibers used for manufacturing filters and gratings.

Aramid yarn
A woven strength member incorporated into fiber optic cable assemblies to provide protection and mechanical bonding. Usually consists of Kevlar™.

Arc
The discharge from the electrodes of a fusion splicer.

Architecture
In networks, it is how the components are connected to and operate with one another. The term "network architecture" focuses on how fiber optic system elements communicate including functional organization (services) and configuration (topology and communications). Network architectures are usually designed as to their protocols. B-PON, G-PON, EPON, GEPON, SONET, ATM, Ethernet, etc., are examples of network architectures.

Armored cable
Cable with metallic sheathing or rods placed under or between cable jackets to prevent rodents from damaging the internal cable elements.

Array connector
Typically, connectors with multiple fibers in a small form factor housing, i.e., MPO, MTP, MT-RJ.

Arrayed waveguide grating (AWG)
A device that allows multiple wavelengths to be combined and separated in a DWDM system.

As-builts
Drawings that provide accurate depictions of cable running lines, pedestal locations, electronic sites, manholes, marker posts, etc., to aid with the management of cable assets and allow the facilities to be located, protected, maintained, and modified.

Attenuation
The loss of optical power, whether caused intrinsically (absorption, scattering, etc.), or extrinsically (connectors, splices, splitters, etc). Expressed as dB or dB/km (with fiber).

Attenuator
A component that incorporates a specific amount of loss into an operational optical network. Attenuators also provide a safety margin in planned networks to allow for electronics degradation over time, or physical changes to the optical component portion of the network. Attenuators come in two styles, fixed and variable. Variable optical attenuators are used for testing systems for dynamic range and quality of signal testing.

Automatic test equipment (ATE)
Test equipment that is computer programmed to perform measurements on a device without changing the test setup.

Avalanche photodiode (APD)
A photodiode that takes advantage of avalanche multiplication of photocurrent to convert one photon to multiple electrons.

Axial ray
A ray passing through the axis of the optical waveguide without any internal reflection.

Backbone
The cabling used to connect entrance facilities, cross-connects, telecommunications closets, and equipment rooms. The backbone may consist of either interbuilding and/or intrabuilding cabling.

Backreflection
The loosely-used term covers optical return loss (ORL) for spans, reflectance for components, and Fresnel reflectance.

Backscatter coefficient
The ratio of the optical pulse power (not energy) at the OTDR output to the backscatter power at the near end of the fiber (z=0). This ratio is inversely proportional to the pulse width, because the optical pulse power is independent. It is expressed in dB.

Backscattering
See *Rayleigh scattering*.

Band
A range of optical spectrum allocated based on optical amplifiers. Six bands are specified by the ITU: O (original), E (enhanced), S (short), C (conventional), L (long), and U (ultra). These cover the optical spectrum from 1260 nm to 1675 nm.

Bandwidth
A measure of the maximum frequency by which light intensity can be modulated before the signal experiences 3 dB of excess attenuation. The difference between the highest and the lowest frequencies of a transmission channel or path; identifies the amount of data that can be sent through a given channel. The greater the bandwidth, the greater the information carrying capacity. Multimode fiber bandwidth is expressed in Megahertz per kilometer (MHz-km).

Baseband
A transmission media where the entire capacity of the cable is used for one signal.

Bayonet
A locking prong and slot interconnect device. The mechanical latching mechanism for the ST-type connector.

Bayonet fiber-optic connector (BFOC)
The formal name for the ST connector, a specific slotted twistlock connector with 2.5-mm ferrule.

Bend-insensitive fiber (BIF)
Single-mode fibers that have been modified to demonstrate reduced bend radius characteristics without attenuation changes. Specified in the ITU-T G.657 standard.

Bend loss
Increased attenuation due to macrobends (curvature of fiber) or microbends (small distortions in the fiber) coupling light energy from the fiber core to the cladding.

Bend radius
The minimum radius that fiber or cable can bend and still maintain its optical and physical qualities.

Biconic
A phenolic-bodied, threaded, spring-loaded, nonkeyed connector with a cone-shaped alignment area.

Bidirectional (Bidi)
Operating in both directions over a single fiber.

Bidirectional transceiver
A device that sends information in one direction and receives information from the opposite direction.

Binder
A tape or thread used for holding assembled cable components in place within loose tube cables.

Bit
An electrical or optical pulse whose presence or absence indicates data. The capacity of the optical waveguide to transmit information without error is expressed in bits per second per unit length.

Bit error rate (BER)
A measurement of transmission accuracy. It is a ratio of bits received in error versus bits sent. Fiber optic communication systems normally have a BER value of 10^{-9} or 10^{-12}.

Bit error rate tester (BERT)
Test equipment that measures the bit error rate (BER) of digital transmission systems.

Bit rate
A unit of measure for digital transmission speeds expressed in bit per second (b/s).

Blocking
Creating a physical barrier to keep moisture-repellent gel in loose tube cables from migrating or flowing out of the buffer tubes into splice trays.

Bonding
A method where all conductive cables and messengers are continuously connected to the grounding network. May also be referred to as continuity bonding.

Boot
Strain relief device consisting of a flexible material on the rear end of a fiber optic connector that protects the cable-to-connector interface from bending damage.

Braid
Textile or metallic filaments that are interwoven to form a flexible tube structure that may be applied over one or more wires, or flattened to form a strap. Kevlar™ is also braided into cables for additional strength.

Breakout cable
A tight buffered cable with 900-micron coated fibers and aramid yarn surrounding each fiber. Jumper cordage is a breakout structure. Available in simplex and duplex variations for jumpers and in large fiber counts. Normally used for indoor installations and for tactical cables.

Breakout kit
A kit that provides a breakout cable structure for non breakout structures (with one fiber per tube).

Bridge
A data communications device that connects two or more network segments and forwards packets between them.

Brillouin scattering
In stimulated Brillouin backscattering (SBS), the laser signal creates periodic regions of altered refractive index; that is, a periodic grating that travels as an acoustic wave away from the signal. This effect can result in a noisy and unstable forward-propagating signal, since much of the optical energy is backscattered.

Broadband PON (B-PON)
The first FTTx standard issued as ITU-T G.983, the B-PON standard was designed for the bidirectional transmission of ATM cells over G.652 single-mode fiber at a distance of 20 kilometers using wavelength independent couplers (splitters) with split rates of up to 1:32. Originally defined by the FSAN S652 document.

Bubble splice
An air bubble in a splice that can cause high loss.

Buffer coating
A protective material with no optical function that covers and protects a fiber. A secondary plastic coating adhered around the coating of the optical fiber to provide additional protection against damage. Normally 250 or 900 microns.

Buffer tube
Part of a loose tube cable structure, buffer tubes accommodate 250-micron coated fibers in a loose configuration. The buffer tubes can be filled with gel, powder, or tapes to resist moisture intrusion.

Bulge splice
Slight overfeed results in bulging at the splice point. Bulging is not always lossy. Splice strength requires a solid fusion joint; monitor splice strength if you are reducing feed to eliminate bulging. Also known as a fat splice.

Buried
Cable placed by trenching, direct burial, plowing, boring, or installation into underground ducts.

Butt closure
Closure with cable ports located at one end of the closure.

Bypass switch
A high-speed switch that transfers an optical signal to an alternate fiber.

Byte
One segment of digital information; usually 8, 16, or 32 bits equal to a single character. Defined with a capital “B” as opposed to “bits”, which uses a lowercase “b”.

Cabinet
A container that may enclose connection devices, terminations, and equipment.

Cable assembly
A fixed length of cable with connectors installed on both ends. Sometimes called a patchcord, patch cable, or jumper.

Cable jacket
The protective outer covering of optical cable. Common materials include polyethylene (PE), polyurethane (PU), polyvinyl chloride (PVC) and Teflon (plenum).

Cable rack
Vertical or horizontal open support attached to a ceiling or wall.

Cable tray
A ladder, trough, solid bottom, or raceway intended for, but not limited to, the support of telecommunications cable.

C-band
The C-band is the “conventional” DWDM transmission band, occupying the 1530 to 1565 nm wavelength range, as specified by the ITU-T G.692. Most EDFAs operate in the C-band.

Center wavelength (CW)
The nominal value operating wavelength in a laser; thereby, the wavelength defined by a peak mode measurement where the effective optical power resides. Also, the average of the two wavelengths measured at half amplitude points of the power spectrum in lasers and LEDs.

Central office (CO)
The building in which telephone companies, etc., locate their switching equipment and terminate their circuits. Sometimes called an “exchange.”

Central strength member (CSM)
A semi-rigid, fibered glass or metallic rod located in the center of a multifiber cable assembly. Usually referred to as dielectric, it provides a directional form for wrapping and stability. This inhibits the buffers from being damaged (stressing the fibers) during the bending of the cable.

Central tube cable
See *Unitube cable.*

Centralized cabling
Provides connections from the work areas to the centralized cross-connect by allowing the use of pull-through cables, an interconnect, or splice in the telecommunications closet.

Chromatic dispersion (CD)
The variation in the velocity of light (group velocity) as a function of wavelength. It causes pulses of a modulated laser source to broaden when traveling within the fiber, up to a point where pulses overlap and bit error rate increases. CD is a limiting factor in high-speed transmission and must be properly compensated, which implies proper testing. A combination of material and waveguide dispersion.

Cladding
The low refractive index material, usually glass, that surrounds and protects the core and provides the optical refractive barrier.

Cleave
A technique where an optical fiber is scratched to produce flat end surfaces that are perpendicular to the longitudinal axis of the fiber. See *scribe.*

Cleave and crimp
A connector installation technique, also known as a no-polish connector. The plug is installed onto the cable with the optic protruding from the end. The cable is crimped to the connector and the optic is cleaved as close to the connector endface as possible.

Cleave tool
A device with a scribing blade, usually made from either diamond or tungsten carbide, used to score a fiber in order to break it without causing a fracture, hackles or angular irregularities. Also known as a cleaver or scribe tool.

Closed circuit television (CCTV)
Video transmissions not provided for public access.

Closure
See *splice closure.*

Coarse wavelength division multiplexing (CWDM)
Applies to greater separation of wavelengths than DWDM. In single-mode applications, CWDM defines a 20-nm separation from 1471 nm to 1611 nm. With multimode fibers, the wavelengths are 778, 800, 825, and 850 nm.

Coating
A plastic or acrylate coating, normally up to 245-250 microns, that is placed over the cladding during the manufacturing process. After this process, the fiber can be colored or upper coated to 900 microns for use in tight buffered cables. See *buffer coating*.

Coaxial cable
A type of cable with a central conductor, an insulator, and a solid or braided shield inside a tough jacket. The inner insulation maintains a constant distance between the central conductor and the shielding, providing a superior quality signal over longer distances.

Coefficient of expansion
The rate that a material or composite object expands or contracts due to temperature changes.

Coherence
Lasers and LEDs emit coherent light waves that are in phase with one another. Coherence describes properties of the correlation between a single wave, or between several waves or wave packets. When interfering, two waves can add together to create a wave of greater amplitude than either one (constructive interference) or subtract from one another to create a wave of lesser amplitude than either one (destructive interference).

Collimation
A process in which a divergent or convergent beam of radiation is converted into a beam with the minimum divergence as possible, preferably parallel.

Color code
A color system for circuit identification by use of solid colors, contrasting stripes, tracers, braids, surface markings, etc., as determined by the TIA-598 standard.

Community antenna television (CATV)
Assumed to be cable television, CATV uses fiber and coaxial media to provide voice, video, or data services.

Competitive local exchange carrier (CLEC)
A company that provides its own network and switching in competition with the already-established ILEC. A newly-formed exchange company in direct competition with the ILEC for the telecom transport market in a specific area. Also known as competitive access provider (CAP).

Composite cable
A cable with a combination of optical fibers and copper (coaxial, twisted pair, or power). Often confused with hybrid cables.

Compression
Any technique for reducing a transmission bandwidth requirement by reduction of the data stream needed to convey the information. Compression standards are identified by MPEG.

Conduit
A pipe made of metal, plastic, or clay used for the installation of communications or power cables between two or more locations.

Cone of acceptance
See *critical angle.*

Connector
Most fiber optic connectors consist of two plugs and one adapter. Connectors can be push/pull types (SC, LC, MPO etc.), bayonet (ST), or threaded (FC). Most use a 2.5-mm ferrule but small form factor types use the smaller 1.25-mm ferrule. Other features include a key and keyway that provide critical alignment for repeatability and for strain relief internally and at the rear boot. Bonding techniques include thermal cure, anaerobic adhesive, and UV adhesive. Splice-on plugs use a prepolished fiber stub and then are mechanically or fusion spliced. Military, industrial, and heavy-duty specialized connectors may use expanded beam lenses and termini contacts (instead of ferrules) based on standard Mil/Aero dimensions. Key specifications for all connectors include attenuation, reflectance, and repeatability.

Consolidation
A step during the optical fiber manufacturing process during which the bait rod is removed and the remaining silica is heated at high temperatures (sintering) to drive out impurities and water and leave only a pure glass rod.

Continuity testing
A test that shows that the optical path is continuous with no breaks.

Continuous wave (CW)
Energy is emitted from a module continuously, rather than in short pulses. CW applications require the laser to be on at all times. Constant output from an optical source that is active but not modulated by a signal.

Controlled environment vault (CEV)
A reinforced vault designed to provide an environmentally-stable underground area to house fiber optic transmission equipment and electronics for switching, monitoring, back-up power, remote terminals, etc.

Cordage
Tight buffered breakout cables used to build patch cords (jumpers). Internally, the fibers are normally one or two 900-micron coated fibers. The term "zipcord" describes a two-fiber cordage to allow two separate plugs to have their own strain relief.

Core
The light guiding part of the fiber with a refractive index higher than that of the cladding.

Core concentricity
A measure of the relationship between the geometric center of the core of an optical fiber and the geometric center of the cladding, or how centered the core is.

Core ovality
A ratio of the minimum to maximum diameters of the core within an optical fiber, or how round the core is.

Coupler
See *splitter.*

Coupling loss
The optical attenuation of a connection or passive device, expressed as a value in dB.

Coupling ratio
A measure of how a device distributes light from its inputs to its outputs. Expressed as either a percentage or in dB.

Crimp sleeve
A sleeve of lightweight metal is deformed by compression to encapsulate material and provide strain relief at the rear of a fiber optic plug.

Critical angle
The minimum angle at which light can be propagated within a fiber. Sine critical angle equals the ratio of the numerical aperture to the index of refraction of the fiber core.

Cross-connect
See *patch panel.*

Cross-phase modulation (XPM)
A nonlinear optical effect where one wavelength of light affects the phase of a similar wavelength of light.

Crush resistance
A test that determines the ability of a fiber optic cable to mechanically and optically withstand the effects of a compressive force. Testing specifies the changes in optical transmittance or attenuation during compressive loading. Specified in the TIA-455-41 "Compressive Loading Resistance of Fiber Optic Cables" fiber optic test procedure.

Curing oven
An oven specifically manufactured to use thermal curing to harden the epoxy injected into a fiber-optic ferrules.

Customer premises equipment (CPE)
The telecommunications terminal equipment located on the customer's premises, including telephones, private branch exchanges, and data terminals.

Cutback method
A technique for measuring fiber attenuation by performing two transmission measurements. One is done at the output end of the full length of the fiber. The other is usually done within 1-3 meters of the input end and accessed by "cutting back" the test fiber and measuring the change in the pre- and post-cutback measurements.

Cutoff wavelength
That wavelength greater than which a particular waveguide mode ceases to be a bound mode. When transmitting lower than a single-mode fiber's cutoff wavelength, the fiber transmits multimode. For G.652 single-mode fibers the cutoff wavelength is 1260 nm. For G.655 fibers, it can range from 1260 nm to 1450 nm.

Dark fiber
An unused fiber installed for future use.

Data communications
The transmission of data from one point to another.

Data link
A fiber optic signal transmission system that carries information in digital or analog form. Usually applies to short-distance communications (less than a kilometer).

dB
A decibel, a logarithmic unit describing the ratio of two powers. Used to measure loss (or attenuation) of quality, reflectance, and amplification of optical signals. The ratio of two power levels, P_1 and P_2, expressed by $-10\log_{10}(P_1/P_2)$.

dB/km
A logarithmic unit describing the ratio of loss of power per kilometer distance. These values are always referenced to a specific wavelength, e.g., 0.35 dB/km at 1310 nm, and are used by fiber and cable manufacturers to define the optical fiber's attenuation.

dBm
Decibels relative to one milliwatt. A positive number indicates the power is above one milliwatt; a negative number indicates the power is below. This unit has become common in fiber optic communication systems because the power of light sources used with optical fibers is on the order of one milliwatt.

Deadzone
An area where an OTDR cannot make measurements. It is limited by the laser's pulse width, the reflection of the front panel connector, and detector circuitry. The shorter the pulse width, the shorter the deadzone.

Deadzone box
A package with internal fiber that is used to test fiber spans with an OTDR, allowing attenuation and connector reflectance to be measured within the OTDR's deadzone. The internal fiber must be at least 20 times the OTDR's minimum pulse width, and they are most commonly sold in lengths of 500 or 1,000 meters.

Demarcation point
The point of interconnection between telephone company terminal equipment and a building's wiring.

Demultiplexer (Demux)
A device that separates the two or more signals that have been combined into a multiplexed signal. An optical demultiplexer separates signals at different wavelengths. An electronic demultiplexer separates signals that have been electronically multiplexed by time (TDM) or frequency (FDM).

Dense wavelength division multiplexing (DWDM)
Specified by ITU-T G.694, DWDM is the transmission of multiple optical wavelengths over a single-mode fiber with spacings of 200 GHz (1.6 nm), 100 GHz (0.8 nm), or 50 GHz (0.4 nm). First implemented in the 1990s, it is mostly used for oceanic, long haul, and metropolitan area networks.

Depressed-clad optical fiber
The inner cladding, next to the core, has a lower index of refraction than the outer cladding region. Depressed refers to the IOR mismatch between the two claddings, resulting in a small MFD that reportedly fusion splices more readily but tends to be less sensitive to the bending losses encountered in most enclosures.

Detector
A device such a photodiode or photodetector that converts optical energy into electrical energy. They can be made from silicon, germanium, gallium arsenide, indium gallium arsenide or from other semiconductors, depending on the wavelengths to detect. The positive-intrinsic-negative (PIN) and the avalanche photodiode (APD) types are used in fiber optics. PIN types can be used for analog or digital systems, while APDs with their internal amplification can only be used in digital systems.

Detector-amplifier
A device in which an optical detector is packaged with electronic amplification circuitry.

Dielectric
An insulating (nonconducting) medium.

Differential group delay (DGD)
A delay caused by different arrival times of optical signals, which results in modal dispersion. In multimode fibers, DGD is the delay difference of the various modes. In single-mode fibers, DGD is the delay caused by chromatic, waveguide, and polarization mode dispersion.

Diffraction grating
An array of fine, parallel, equally-spaced reflecting or transmitting lines that mutually enhance the effects of diffraction to concentrate the diffracted light in a few directions determined by the spacing of the lines and by the wavelength of the light.

Digital
A data format that uses discrete varying signals to contain information. Used in fiber optics as this format is easier to process and multiplex, and it is less sensitive to noise than analog transmission.

Digital signal (DS)
A hierarchy of digital signal speeds used to classify capacities of digital lines and trunks. The fundamental speed level is DS-0 (64 kb/s).

Digital subscriber line (DSL)
A generic name for a family of digital lines provided by local telephone companies to their subscribers.

Diode adapter receptacle
Designed to house LED or PIN/APD diodes in a receptacle that allows the mating plug to position the fiber for an optimum coupling efficiency.

Diplexer
A component used to provide two functions, such as multiplexing or filtering optical signals. For example, a diplexer used at an FTTx optical network terminal filters the downstream 1490-nm wavelength and multiplexes the upstream 1310-nm wavelength to or from a single fiber.

Direct buried
See *buried.*

Directional coupler
A fiber optic coupler that preferentially transmits light in one direction.

Directionality
A quantification of how much light is passing in any direction, measured in dB. If a 0 dBm signal passes through a coupler with 50 dB directionality, only −50 dB (0.01 μm) will pass in the wrong direction.

Directly-modulated laser (DML)
A laser directly modulated by electrical voltage and current.

Dispersion
The cause of bandwidth limitations in fiber. In multimode systems, modal dispersion is caused by differential optical path lengths known as differential path delay. For single-mode systems, chromatic dispersion is a combination of material dispersion (caused by the line width of the laser source) and waveguide dispersion (caused by the difference in the speed of light in the core and the cladding of the fiber). Another type of dispersion is polarization mode dispersion (PMD), which is caused by random vibration, temperature variations, and bending of the fibers known as birefringence.

Dispersion-compensating fiber (DCF)
A type of specialized fiber designed to offset or compensate for chromatic dispersion in single-mode fibers.

Dispersion compensation module (DCM)
Dispersion compensation modules use a chirped fiber Bragg grating (FBG) and a optical circulator, which act as an individual wavelength or channel filter. Faster wavelengths are reflected further in the filter than slower wavelengths, enabling the slower wavelengths to catch up. The amount of delay is determined by the physical characteristics of the FBG. DCMs typically have insertion losses around 5 dB, consisting only of circulator and reflection losses. Tunable versions are also available.

Dispersion-shifted fiber (DSF)
Specified by ITU-T G.653, this fiber provides low attenuation and dispersion at 1550 nm. It could not be used with DWDM as it caused four wave mixing, and has been obsoleted and replaced by G.655 nonzero dispersion-shifted (NZDS) fiber.

Distributed feedback (DFB) laser
A laser that uses an internal grating to reduce the line width of the laser, and may be used for analog applications, e.g., AM/FM/DWDM.

Distribution cable
A tight-buffered non breakout style cable mostly used for indoor installations. Jackets can be plenum, riser, or low smoke zero halogen to meet building codes. Internally, the fibers have a 900-micron coating. In the outside plant, the term “distribution cable” is used by service providers to describe the cable between the feeder (backbone) and drop cables.

Distribution panel
A combination of a patch panel and splice panel.

DOCSIS
The Data-Over-Cable-Service Interface Specification that permits a cable modem termination system to be designed as either a layer 3 router or layer 2 switch. Used by the CATV industry.

Dopant
A material, usually germanium or boron oxide, added to silica to change its index of refraction.

Doping
Controlled addition of small quantities of an impurity to a pure substance in order to change its characteristics, e.g., increase the refractive index of the fiber core.

Draw
A step during the optical fiber manufacturing process in which a consolidated preform is loaded into a high temperature furnace and “drawn down” to the diameter of an optical fiber’s cladding, then cooled.

Dry fit
It is when fiber is inserted into a plug’s ferrule or termini to verify the strip length and fit prior to insertion of the bonding adhesive. This helps the technician to recognize the “feel” of the fiber insertion process.

Dual in-line package (DIP)
Only refers to pigtailed dual in-line packaged devices.

Duct
A small pathway, generally 4” or smaller in diameter. Smaller inner ducts or Maxcell are installed to allow cables to be pulled through. It may be buried, installed aerially, or within a building. Common types include smoothwall, ribbed, and corrugated.

Duplex
Two; twin. Refers to the type of fiber optic cable, e.g., duplex zipcord, or duplex plug, e.g., SC, LC.

Duplex transmission
Transmission in both directions, either one direction at a time (half duplex) or both directions simultaneously (full duplex).

Dust cap
A protective cover that fits tightly over the connector ferrule, plug, or sleeve. Usually made of plastic, it is used to keep the connector endface clean.

Dynamic range
For an optical instrument, defined (in dB) as the ratio of the smallest signal that can be observed at a specified wavelength separation in the presence of a strong nearly-saturating signal.

E-band
Defined by ITU-T G.692 as “extended” for wavelengths between 1360 and 1460 nm. This band includes the high OH peak in single-mode fibers. G.652D fiber is designed for transmission within the extended band. In FTTx systems, the term can be confused with the enhancement band, which the ITU-T G.983 and G.984 PON FTTx standards define as the wavelengths between 1550 and 1560 nm for RF overlay transmission of video signals.

Edge-emitting diode (ELED)
A diode that emits lights from the edge of a semiconductor chip, producing higher power and narrower spectral width.

Electrode
The device in a fusion splicer that discharges the electric energy, fusing two or more fibers together.

Electromagnetic interference (EMI)
The frequency spectrum of electromagnetic radiation that extends from subsonic frequency to X-rays. Not to be used in place of “RFI”.

Electromagnetic pulse (EMP)
An extremely strong but short-lived magnetic field that results from a solar flare or nuclear explosion. A high-altitude explosion could cause a damaging magnetic field up to 3000 miles away.

Emergency restoration kit (ERK)
A kit consisting of a length of optical cable, two closures, splice products, tools, and fixtures to assist in temporary or permanent restoration of cable repairs.

Encircled flux (EF)
Defined by IEC 14763, TIA 455-203, and IEEE 802.3ae, EF is the most accurate test for determining optical attenuation for multimode fibers. Most often used in factory environments due to its complexity and equipment costs.

Endface
The surface area of the fiber optic ferrule where the optical fiber is centered and polished.

End finish
Surface condition at the optical plug/ferrule end.

End separation loss
The optical power loss caused by distance between the end of a fiber and a source, detector, or another fiber.

Entrance facility
The entrance to a building for communications and power. It provides the transition between the outside plant and the premises. The entrance facility can connect to telecom, utility, or communication rooms or closets.

Epoxy
An adhesive that uses chemical reaction to "cure" or "dry", bonding two materials together.

Epoxyless connector
A connector that requires no epoxy to hold the optical fiber to the connector.

Equilibrium modal distribution (EMD)
Steady-state modal distribution in multimode fiber, achieved some distance from the source, where the relative power in the modes becomes stable with increasing distance.

Erbium-doped fiber amplifier (EDFA)
An optical amplifier that uses active erbium-doped fiber and a pump source (laser) to boost or amplify the optical signal. Used in DWDM, CATV HFC, RF overlay and RFoG systems. Amplifies mostly in the C-band (1530 to 1565 nm).

Ethernet
A data communications protocol for premises and local access networks, Ethernet features variable length packets that allow data to be sent with less overhead.

Ethernet PON (EPON)
Based on IEEE 802.3ah protocol for Ethernet, EPON is a network data transport using a variable length packet structure up to 1,518 bytes at data rates up to 1,000 Mb/s over single-mode fiber. The EPON format uses up to 1:32 optical splitters and can use either one fiber bidirectionally (BX) or two fibers (LX) in low medium or high power configurations.

Excess loss
The amount of light lost in a coupler, beyond that inherent in the splitting to multiple output fibers.

Extrinsic loss
Loss caused by imperfect alignment of fibers in a connector or splice such as lateral offset, angular misalignment, end separation, and end finish.

Fabry-Perot (FP) laser
A multilongitudinal mode laser diode with a semiconductor on each end to form a resonant chamber to create the lasing effect. Used in digital applications. Limited to 10 Gb/s speeds and used only for digital transmission.

Fanout kit
A kit designed for loose tube cable structures with multiple fibers per buffer tube. The fanout kit provides a 900-µm tubing over each 250-µm coated fiber strand, which allows for additional protection.

Fast Ethernet
IEEE 802.3 standard operating at 100 Mb/s.

Fault
Break or stress in the continuity of the optical fiber's normal performance.

Fault finder
A simplified OTDR used to locate breaks in spans of fiber. See *fiber break locator*.

Ferrule
Most often made of ceramic, but can also be steel or plastic. The fiber is bonded internally to the ferrule, which provides the alignment with the mating sleeve and opposite ferrule. Ferrule endfaces can be flat, radiused, or angled depending on the type of fiber and endface polish.

Fiber
A single optical transmission element characterized by a core, a cladding, and a coating. Two common structures, single-mode (with a step-index profile) or multimode (with a graded-index profile) are used for fiber optic communication systems. Different variations are made depending on the attenuation, bandwidth, dispersion, wavelengths, and mechanical requirements.

Fiber amplifier
Most common are the erbium doped fiber amplifiers (EDFAs), semiconductor optical amplifiers (SOAs), and Raman amplifiers, which are used to increase signal gain without electrical conversion.

Fiber Bragg grating (FBG)
A piece of photo-refractive fiber that is exposed to high-intensity UV interference patterns, causing it to reflect a specific wavelength while being transparent to all other wavelengths. Used as a filter in WDM systems.

Fiber break locator
A low-cost OTDR used to locate breaks in optical cables.

Fiber coating
A UV-cured material immediately surrounding the glass cladding that serves to protect the integrity of the fiber from surface damage and stresses. Normally 250 μm for outside plant cables and 900 μm for indoor cables.

Fiber connector (FC)
A keyed connector with threaded coupling mechanism that has 2.5-mm ferrule. Mostly used in single-mode systems and test equipment.

Fiber demarcation box (FDB)
A fiber demarcation box provides a service provider with a customer disconnection point, either via a splice or connector interface. Slack cable storage and battery backup are stored here as well.

Fiber distributed data interface (FDDI)
A duplex, counter-rotating, and self-healing ring communication standard (ANSI X3T9) that provides a 100 Mb/s data format. Often used to interconnect low-speed protocols such as Token Ring and Ethernet.

Fiber distribution unit (FDU)
Enclosures that house and organize groups of fibers.

Fiber optic cable
A communications cable that consists of one or more optical fibers, each capable of transmitting data via modulated light waves. Loose buffered types for outside plant applications can be armored or dielectric stranded or central tube designs. Applications include aerial figure-8, ducted, direct buried, all dielectric self-supporting (ADSS), and optical power ground wire (OPGW). Indoor designs are tight buffered breakout or distribution types with cable jackets designed to meet building codes for use in plenum, riser, and low smoke zero halogen environments.

Fiber optic test procedure (FOTP)
Standardized methods for testing various fiber optic components, as specified in the TIA-455 standard.

Fiber optics
The links used for voice, video, data, medical, sensing, and illumination applications. All use optical fibers to transmit or receive optical signals or power.

Fiber proof testing
A mechanical tensile test used to measure the axial strength of an optical fiber, normally 100 kpsi.

Fiber sensor
A sensing device in which the active sensing element is an optical element attached directly to an optical fiber. The measured quantity changes the optical properties of the fiber so that it can be detected and measured.

Fiber surface finish
The quality of the polishing at the end of the fiber (1 mm, 0.3 mm, etc.). Some terms that describe a poor surface finish are: mist, hackle, chipped, or cracked.

Fiber to the antenna (FTTA)
See *fiber to the cell.*

Fiber to the building/business (FTTB)
A topological reference to a network that supports multiple subscribers in a single structure, i.e., a business or a building. Multiple dwelling unit (MDU) defines residential use and multiple tenant unit (MTU) defines business units.

Fiber to the cell (FTTCell)
Fiber to the cell tower. Used to provide greater bandwidth and to transition to IP requirements using Ethernet.

Fiber to the curb/customer (FTTC)
Distribution of communication services by providing fiber optic links to a central point in each neighborhood and continuing to the homes by either twisted pair or coax.

Fiber to the desk (FTTD)
Transmission system using fiber optics from transmitter to desktop.

Fiber to the home (FTTH)
Distribution of communication services by providing fiber optic links all the way to each house. Protocols include active Ethernet and PON systems as defined by the IEEE, ITU, and SCTE.

Fiber to the node (FTTN)
An access network in which fiber is used for part, but not all, of the link from the OLT to the end user. An optical-to-electrical conversion takes place at a node, which typically serves a neighborhood. The terminal network segment is usually twisted copper pair (FTTC) or coaxial cable (HFC). Most current CATV and telephony networks have FTTN architectures.

Fibre Channel
A high-speed interconnection ANSI standard for connecting supercomputers with peripheral devices up to 10 km away at transmission rates over 1 Gb/s. Used for the broadcast industry, storage area networks, and data centers.

Figure-8 cable
A type of cable with a built-in messenger designed for aerial installations.

Figure-8 polishing
When a connector is polished on a lapping film/plate combination in a Figure-8 pattern to minimize scratches by using a different area of the lapping film.

Fillers
Nonconducting components cabled with optical fibers to impart roundness, flexibility, tensile strength, or a combination of all three to the cable.

Firestop
A material, device, or assembly of parts installed within a cable system in a fire-rated wall or floor to prevent the passage of flame, smoke, or gases through the rated barrier.

Five nines
Any system operating 99.999% of the time.

Flat polish
A highly-reflection ferrule endface condition where fiber optic and ferrule tip are polished flat. Normally used with multimode fibers.

Forward error correction (FEC)
A method to improve the performance of large-capacity optical transmission systems. System designs employing FEC can accept relatively large BER (better than 10^{-12}) in the optical transmission line before encoding.

Four wave mixing (FWM)
A collective name for a group of nonlinear processes where up to three different incident waves interact in the medium, resulting in a fourth wave.

Frequency
The number of cycles per unit of time, denoted by Hertz (Hz); 1 Hertz = 1 cycle per second.

Frequency division multiplexing (FDM)
Two or more signals combined at different frequencies so they can be transmitted as one signal.

Frequency modulation (FM)
A modulation scheme in which the message signal modulates a carrier signal so that the frequency (as opposed to the amplitude or phase) of the carrier is varied.

Fresnel reflection
Reflection of a portion of the incident light at a planar interface between connectors, mechanical splices, or two homogeneous media having different refractive indices.

Full width half maximum (FWHM)
Used to measure the spectral width of light sources. Measure the spectral width at 3 dB (half power from peak) and at the full width of the source's power peak.

Fusion splicer
A mechanical device that optically joins optical fibers by discharging voltage between two electrodes. Variations include the single fiber and ribbon fixed V-groove types, the profile alignment splicer (PAS) and the local injection detection (LID), both of which are categorized as core alignment splicers.

Gain
Increased backscatter inherent within OTDR. Fiber measurements due to different core sizes or core mismatch. A gainer refers to an OTDR signature that shows splice loss in one direction and "gain" of the reflected signal in the opposite direction.

Gateway
A computer that connects and translates protocols between disparate types of networks.

Ghost
An OTDR signature caused by an optical echo that occurs when light reflects off two reflective surfaces, creating a false image at double the distance from the initial event.

Giga (G)
A prefix meaning one billion.

Gigabit Ethernet
IEEE 802.3z. A standard for a high-speed Ethernet, capable of transmitting data at one billion bits per second. It provides increased network bandwidth and interoperability, and can be used in backbone environments to interconnect multiple lower-speed Ethernet systems.

Gigabit PON (G-PON)
Standardized in ITU-T G.984, G-PON handles data rates up to 2.5 Gb/s and allows split ratios up to 1:64. The standard features the G-PON encapsulation method (GEM), which allows for the transmission of Ethernet packets and ATM cells.

Gigahertz (GHz)
A unit of frequency equal to one billion Hertz.

Glass blank
The pure, solid glass mass formed after sintering an oxide preform. This glass blank undergoes a drawing process to become optical fiber.

G-PON encapsulation method (GEM)
A method of data encapsulation over the G-PON network, similar to ATM, that uses variable length frames to transport up to an encapsulated payload of 1500 bytes. Capable of sending ATM cells or Ethernet packets over the network.

Graded-index multimode fiber (GI-MMF)
A type of multimode fiber where the refractive index of the fiber core decreases radically towards the outside of the fiber. Four types of GI-MMF have been specified in IEC 60793-2: legacy OM1 (62.5/125) and OM2 (50/125) fibers and the newer, high bandwidth, laser-optimized OM3 and OM4 fiber (both 50/125), designed for VCSEL lasers and Gigabit data rates.

Greenfield
Network deployment in an area under development. Since everything is being built for the first time, network construction can be done with few obstructions and installation can be accomplished parallel to other utilities.

Ground
An electrical connection to the earth, generally through a ground rod.

Group delay (GD)
The difference in arrival time between wavelengths.

Handhole
An access opening provided in equipment or in a below-the-surface enclosure into which personnel reach, but do not enter, to work with or place cable. Also known as maintenance access handhole.

Head end
Central distribution point for a CATV system where a link is created between the HFC system and any external data networks. Video signals are received and frequency is converted to the appropriate channels, combined with locally originated signals, and then rebroadcast.

High definition television (HDTV)
Digital television with significantly more resolution than that provided by a good NTSC or PAL television signal. The specific resolution can vary, however it is typically about twice the resolution of standard television signals, and has a wider aspect ratio.

High-density connector
Typically, connectors with multiple fibers in a small form factor housing, i.e., MPO/MTP, MT-RJ.

High-density polyethylene (HDPE)
A jacketing material used in harsh environments to protect cables from accidental chemical exposure.

Home run
A PON architecture where the optical splitter is housed at the service provider's facility. Home runs are the easiest for handling changes, but require a fiber rich cabling system as one fiber is dedicated for each subscriber.

Horizontal cabling
Cabling that extends between and includes the horizontal cross-connect and the telecommunications outlet.

Horizontal cross-connect (HC)
A cross-connect of horizontal cabling to other cabling, e.g., horizontal, backbone or equipment. Could be a patch panel or LAN (small) panel.

Hot melt
A type of connector pre-loaded with epoxy. The connector must be heated to liquefy epoxy for fiber optic insertion. The ferrule is then cooled to re-harden the epoxy. Manufactured by 3M.

Hub
In LANs, a hub is the core of a star, a central point on a network where circuits are connected. In ITS systems, it is a small building or hut located along a roadway or under bridges, which is used to consolidate video and data signals between the traffic management center and distributed to roadside cameras, DMS, VMS, or traffic control systems.

Hybrid cable
A cable with multiple types of optical fibers (e.g., multimode and single-mode). Often confused with composite cable.

Hybrid cable assembly
A jumper assembly with different connections on each end.

Hybrid fiber coax (HFC)
A hybrid system, used by the CATV industry, that employs a fiber optic backbone and coax cables for final distribution from the node to the customer.

IckyPic
The gel added inside a cable that to prevent water penetration. Used in outdoor cables.

Impact resistance
A test that determines the ability of fiber optic cables and cable assemblies to withstand repeated impact loads. It measures the number of broken fibers, damage to the outer sheath, and any change in the optical transmittance or attenuation. Specified in the TIA 455-25 "Repeated Impact testing of Fiber Optic Cables and Cable Assemblies" fiber optic test procedure.

Incumbent local exchange carrier (ILEC)
The dominant phone carrier within a geographic area that provides local exchange service to that area.

Index matching fluid
A gel or liquid material whose index of refraction is almost equal to that of the fiber core. It is used to reduce Fresnel reflections in mechanical splices or cleave and crimp connectors.

Index of refraction (IOR)
The ratio of the speed of light in a vacuum to the speed of light in a material. When light strikes the surface of a transparent material, some light is reflected while some is bent (refracted) as it enters. The IOR is used to calibrate OTDRs for measuring fiber length.

Indium gallium arsenide (InGaAs)
The components of crystalline semiconductors used in fiber optic photodetectors.

Infrared
Light wavelengths extending from 770 nm on.

Inline splice closure
Closure that has cable ports at opposite ends.

Innerduct
Usually a nonmetallic pathway that may be placed within a duct to facilitate initial and subsequent placement of multiple cables in a single duct.

Insertion loss
Total optical power loss caused by the insertion of an optical component such as a connector, splice or splitter. Measured in dB.

Inspection scope
A microscope or digital scope that inspects ferrule and termini fiber endfaces for polishing quality, damage, or contamination.

Institute of Electrical and Electronics Engineers
IEEE is a standards organization representing the United States on the ISO in the areas of electrical or electronic standards. Writes standards on communications including Ethernet and OPGW and ADSS cables.

Insulated Cable Engineers Association
ICEA is a professional society that promotes the reliability of covered and insulated conductors for the transmission and distribution of electric energy, control, and instrumentation of equipment and communications.

Interbuilding backbone
A network that provides communications between buildings, e.g., college campus, office park, etc.

Interconnection
A scheme that provides for the direct connection of a cable to the other cable without a patchcord or jumper.

Interexchange carrier (IXC)
Any common carrier that provides long-distance services, i.e., Sprint or AT&T.

Interference bands
Measured on an interferometer, the dark lines or "bands" optically projected across the face of an object to determine its shape by means of measured elevation.

Interferometer
A measurement instrument that projects interference bands across the face of fiber optic connector. The bands are used to determine the centering, angle of apex offset and radius of curvature of the fiber optic connector.

Intermediate cross-connect (IC)
A cross-connect between first and second level backbone cabling. It can be between main (MC) and horizontal (HC). Normally would consist of a patch panel.

Intermediate distribution frame (IDF)
A metal rack located in an equipment room or closet that is designed to connect cables. It consists of components that provide the connection between interbuilding cabling and the intrabuilding cabling.

International Electrotechnical Commission (IEC)
An international standards body responsible for recommendations and standards for telecommunications.

International Standards Organization (ISO)
An international body funded by the United Nations, that provides consistent worldwide standards. U.S. membership is provided by ANSI.

International Telecommunications Union (ITU)
International body for communications standards. The telecommunications group within ITU is designated as ITU-T.

Internet protocol (IP)
A set of rules for how data is transmitted from place to place on the Internet. IP is a connectionless protocol in which data is broken down into small bundles known as packets. Each packet is transmitted separately, possibly along a different route than other packets from the same message.

Internet protocol television (IPTV)
A compressed digitized video provided through packet or cell transmission (FTTH) to subscribers.

Internet service provider (ISP)
An organization whose business is connecting users to the Internet. By serving as the interface between end users and the Internet, the ISP's equipment is analogous to a CATV head end or telephony CO.

Intrabuilding backbone
A network that provides communications within a building; often referred to as the riser backbone in vertical buildings.

Intrinsic losses
Losses arising from differences in fiber tolerances.

Isolator
A passive fiber optic component that either allows only unidirectional passing of light or that passes only some wavelengths of light. Used in conjunction with lasers or optical amplifiers to reduce or remove backreflections.

Jacketing
The outer jacket of a cable, which can be made from a variety of materials including but not limited to HDPE, MDPE, PVC, *et. al.*

Jitter
The variation in time of a received signal compared to the instance of its transmission or compared to a fixed time frame at the receiver. Examples of jitter sources include signal-pattern-dependent laser turn-on delay jitter, noise-induced jitter on a gating turn-on point, gating hysteresis jitter, and gating jitter that accumulates in a link between two nodes.

Jumper
See *patchcord.*

Kellems grip
Wire, aramid or synthetic mesh that is placed around the cable to be installed, intended to provide positive pulling power. Also known as pulling or mesh grips.

Kevlar™
Strands of protective aramid fiber used to provide strain relief in cable assemblies. Also used in cables as their dominant means of strain relief. Kevlar is a trademarked name by DuPont.

Keyed
Connectors in which the plug and adapter are fixed in alignment to prevent rotation and fiber endface damage.

Kilo (k)
Numerical prefix denoting one thousand.

Kilometer (km)
Standard length of measurement for fiber optics; 1,000 meters, 3,281 feet, or 0.621 miles.

kpsi
Tensile strength measured in thousands of pounds per square inch.

Lapping film
Sheets of a thin plastic film with grit of varying coarseness (in microns) that are used to polish fiber endfaces.

Large core fiber
An optical fiber with a comparatively large core, usually a step-index type. Generally considered as fibers with diameters of 400 microns or more.

Laser
Light amplification by stimulated emission of radiation; a coherent source of light with a narrow spectral width.

Laser chirp
Noise created by reflected or crosstalk optical energy entering the lasing chamber.

Laser diode
A semiconductor diode that emits light in a narrow spectrum; typically over 90% of the light output power concentrated within one angstrom.

Laser-optimized multimode fiber
The ISO/IEC 11801 standard defines two types: the OM3 50/125 fiber, with an effective modal bandwidth of 2,000 MHz-km at 850 nm, and the OM4 50/125 fiber, with 4,700 MHz-km bandwidth.

Lashing
Wrapping a cable and its supporting strand or cable together via a steel or dielectric filament.

Last mile
The last mile is the local access network that extends from the CO to the end-user subscriber. Also called the local loop network, it is traditionally copper-based and suffers from the bandwidth limitations of that media.

Latency
Delay of a signal in time, which can be caused by transmission, processing, rotation, and propagation delays.

Laydown
A step during the optical fiber manufacturing process in which gases are deposited as a wet "soot" upon a quartz rod by flame hydrolysis, ultimately creating a preform for the glass core and cladding of an optical fiber.

L-band
The "long" DWDM transmission band, occupying the 1565 nm to 1625 nm wavelength range.

Least square approximation (LSA)
A technique used by OTDRs to automatically measure splice attenuation.

Light
The region of the electromagnetic spectrum that can be perceived by human vision, designated by the visible spectrum and nominally covering the wavelength range of 400-770 nm. In optical communications, it includes the much broader portion of the electromagnetic spectrum that can be handled by the basic optical techniques used for the visible spectrum. This region is not clearly defined but may be considered to extend from the near-ultraviolet region of approximately 300 nm, through the visible region, and into the mid-infrared region to 30,000 nm.

Light-emitting diode (LED)
A semiconductor device that emits incoherent light formed by the P-N junction. Burrus (well) and edge-emitting diodes are used with systems operating up to 622 Mb/s over multimode fibers.

Light source
The fiber optic transmitter in an optical loss test set (OLTS) that uses one or more LEDs or lasers at specified wavelength. Lasers used in communication systems must be stabilized and operating in continuous wave or modulated at 2 kHz.

Lightguide
See *waveguide.*

Link
An optical cable with connectors attached to a transmitter and receiver.

Local access and transport area (LATA)
The geographic area that is the domain of the local exchange carrier. Bell operating companies are generally precluded from carrying traffic across LATA boundaries; this traffic must be handed off to an interexchange carrier.

Local area network (LAN)
An interconnected system of separate stations, usually computers, in a relatively small geographical location such as an office building or campus.

Local exchange carrier (LEC)
The phone carrier providing local transmission services. Defined as either Independent or regional Bell operating company (RBOC).

Local injection and detection (LID)
A core alignment fusion splicer that injects light through a macrobend prior to the splice point and detects the light through a macrobend past the splice point. This allows the splicer to achieve maximum core-to-core alignment.

Local loop
The connection between a customer's telephone or data equipment and a local exchange company or other telephone service provider.

Long wavelength
Light in the 1300-nm, 1550-nm, and 1625-nm wavelengths

Loose tube cable
A type of cable where the internal 250-micron fibers are loose within buffer tubes. Types include stranded, central tube, OPGW, ADSS, and microduct cable. Also known as loose buffer cable.

Loose tube gel filled (LTGF)
A loose tube cable structure with buffer tubes filled with gel to restrict moisture intrusion. Mostly replaced with "dry" techniques, it is still used in areas of extreme low temperatures.

Loosely-coupled mode
One example would be a high order mode from a LED coupled into a multimode fiber. Higher order modes limit the bandwidth of optical fibers.

Loss
See *attenuation.*

Loss budget
The tolerable difference between the light impulse where it originates and the light impulse where it arrives at the receiving end. If too much light power has been lost along the way through deficiencies in the cable or connectors, the signal cannot be read and interpreted.

Loss windows
Fiber optic transmission typically occurs at 850, 1300/1310, 1550, and/or 1625 nm. These "windows" were selected because absorption and scattering losses were lower within them. These wavelengths require light sources and photodetectors that operate efficiently over multimode and single-mode fibers. The newer term "bands" is used to define optical windows that match up with optical amplifiers and their optimum transmission wavelengths. The history of the usage comes from the availability of sources and detectors and their operating characteristics over an optical fiber due to the absorption effects at different wavelengths.

Low-smoke zero halogen (LSZH) cable
The standard cable used in Europe in place of plenum or riser cable types. Internationally, LSZH cables are used in place of plenum and riser cable jackets. In North America, LSZH cables are used on ships and in tunnels. Also known as zero halogen cable.

Machine polishers
Automated polishers that are capable of polishing from two to 32 connectors at one time. These polishers can provide uniform low reflection polishes (e.g., PC, SPC, UPC, APC).

Macrobending
In an optical fiber, all macroscopic deviations of the axis from a straight line; distinguished from microbending.

Main cross-connect (MC)
A cross-connect for first and second level cabling, e.g., from equipment facility connecting to all other locations (ICs and HCs). Usually a distribution or patch panel.

Main distribution frame (MDF)
A wiring arrangement that connects the outside telephone lines on one side to the internal lines on the other. A main distribution frame may also carry protective devices as well as function as a central testing point.

Mainframe OTDR
An OTDR with a larger chassis than a mini OTDR. Mainframe OTDRs have CRT displays, internal printers and are larger and heavier than most OTDRs. They were the most common type up till the early 1990s. Mainframes could also be provided with different laser and fiber modules as needed.

Mandrel
A mechanical device of a specific diameter that strips out higher order modes from multimode fibers.

Margin
The amount of additional loss that can be tolerated in a link.

Matched-clad optical fiber
Optical fiber with a cladding of consistent refractive index up to the core boundary, resulting in the desired single-mode step-index profile. Used where fibers of different periods are spliced together as they produce lower attenuation readings and are less susceptible to bending losses.

Material dispersion
Dispersion caused by differential delay of various wavelengths of light in a waveguide material.

MaxCell
A type of flexible fabric inner duct used to increase capacity of ducts.

Mean time between failure (MTBF)
Developed by the military to estimate maintenance or replacement times for various pieces of high-end equipment, MTBF is based upon statistical evidence derived from in-use testing under extreme conditions (simulated or actual environment). Testing is performed by the manufacturer of the equipment or an independent test facility.

Mechanical splice
A fiber splice accomplished by fixtures or materials, rather than by thermal fusion. Index matching material may be applied between the two fiber ends.

Media outlet
A small patch panel located at work areas allowing quick termination of voice, video, and data connectors.

Medium-density polyethylene (MDPE)
A flexible, environmentally-stable thermoplastic used in outside cable jacketing.

Mega (M)
A prefix meaning one million.

Megabit (Mb)
One million bits.

Messenger wire
Galvanized wire ranging from 1/4" to 9/16" which is placed between poles and which standard cable types are lashed.

Metropolitan area network (MAN)
An interconnected data transmission system connecting users and LANs in localized geographical areas such as a city.

Microbending
An effect where small stresses or flaws create attenuation. Mostly an extrinsic effect caused by tie wraps and point deformations onto the fiber that allow light to escape. Intrinsic sources are flaws or defects in the core/cladding boundary created during the manufacturing process.

Microduct
Small HDPE ducts up to 16 mm in diameter that can be installed in empty or partially filled ducts to provide space for microduct fiber optic cables.

Microduct cable
Microduct cables are designed for high-density fiber counts in a small optical cable, normally between 5-16 mm. Designed for blowing into microducts.

Micron (µm)
A millionth (10^{-6}) of a meter. A common unit of measurement for fiber optic diameters.

Mid-entry
Opening a cable in the middle of a span to access the fibers. Also known as an express entry.

Military tactical cable
Heavy-duty cable designed for rugged installations and operations.

minEMBc
An abbreviation for minimum calculated effective modal bandwidth, minEMBc is used to calculate the bandwidth of multimode fiber at Gigabit data rates.

Mini OTDR
Mini OTDRs emerged in the 1990s as a low-cost, lightweight version of the mainframe OTDR. Features include AC/DC power, LCD display, and various modules for specific fiber types and corresponding wavelengths. Usually without a printer, they can store traces on disk, memory card, or their internal hard disk.

Mini Zipcord
A separable two-fiber breakout style cable.

Modal dispersion
In multimode fibers, there are axial, lower, and higher order modes that cause modal dispersion, thereby limiting effective transmission distance. Because axial modes arrive sooner than higher order modes, this causes the pulse to spread. See *differential mode delay.*

Mode
A light path.

Mode conditioning patchcord (MCPC)
Designed for GbE and Fibre Channel links using legacy multimode fibers and VCSEL light sources operating at 850 nm. Normally it is a pair of duplex jumpers that are installed between the transmission equipment at each end of the fiber link. The transmit side has a short single-mode section "offset" fusion spliced to MMF so the light is coupled outside of the center core defect of the MMF. The receiver portion is entirely multimode.

Mode field diameter (MFD)
The portion of a single-mode fiber that actually transmits the light energy. Generally 20% larger than the physical core. The size of the mode field varies with wavelength.

Mode filter
A device to remove high order modes to simulate equilibrium mode distribution in a short length of optical fiber.

Mode power distribution (MPD)
The relative mode power in each mode groups of a multimode fiber.

Mode scrambler
A device for inducing mode coupling in an optical fiber.

Modulated laser
A laser module that allows users to control output power by varying a control voltage, which turns the laser on and off.

Modulation
The coding of information onto a carrier frequency. May use amplitude, frequency, phase, or time, plus many forms of on/off digital coding.

Modulator
A waveguide device used externally to the laser to electro-optically change the refractive index of the waveguide in response to an applied electric field. The phase changes induced can result in amplitude modulation of light at the output port.

Monomode
See *single-mode.*

Moving Pictures Experts Group (MPEG)
Various standards, established by the, that define the amount of compression, and thereby the quality, of the resultant video information file.

Multifiber cable
An optical cable having more than one fiber.

Multifiber push-on connector (MPO)
A high-density connector that can terminate up to 24 single-mode or 72 multimode fibers in a single termination.

Multilongitudinal mode (MLM) laser
A laser, usually Fabry-Perot, that has a measured spectral width specified by the maximum root mean square of the spectral distribution (side modes), limited to no more than 20 dB down from the peak mode.

Multimode fiber (MMF)
An optical waveguide that allows more than one mode to be guided. 50/125, 62.5/125 and 100/140 are the most common. Graded-index types are used in fiber optic communication systems.

Multiple system operator (MSO)
A cable television provider.

Multiplex
A concept in which independent sources of information are combined and transmitted over a single communication channel. Electronic multiplexing includes TDM and FDM, while optical multiplexing includes wide, coarse, and dense wavelength division multiplexing.

Multiplexer (Mux)
A device which combines two or more separate signals for transmission through a single fiber. Optical multiplexer combines signals at different wavelengths. Electronic multiplexer combines TDM or FDM signals electronically before they are converted into optical form.

Multitenant data center (MTDC)
A facility that provides Internet infrastructure services, such as electrical power, fire suppression, security, cooling, and network access, usually over optical fiber. Some firms lease datacenter space to other providers or individual enterprises. Colocation data centers sell space on the basis of racks, cabinets, or cages.

Multiuser telecommunications outlet assembly (MUTOA)
Used in work areas of premises networks to allow multiple terminations.

Nanometer (nm)
One billionth of a meter, or 10^{-9} meters. Most common unit of measurement for light.

Nanosecond (ns)
One billionth of a second, expressed as 10^{-9} seconds.

National Electrical Code (NEC)
A North American code that addresses proper electrical/fiber optic systems and equipment installation to protect people and property from hazards stemming from the use of those systems in buildings and structures. Updated every three years. In Canada, refer to the Canadian Electrical Code (CEC).

National Electrical Safety Code (NESC)
This outside plant code contains basic safety provisions that cover supply, communication lines, equipment, and work practices of personnel employed by utilities.

National Institute of Standards and Technology (NIST)
A U.S. government organization that develops standards in support of industry, commerce, scientific institutions, and all branches of government. The calibration of test equipment is traceable to NIST equipment.

National Television Standards Committee (NTSC)
Committee that defines specifications and methods for displaying video information on a standard television.

Neck splice
Necking or narrowing produces a high loss splice. Also caused by bad cleaves which leave a void between the fiber ends resulting in a narrow section during fusion.

Network access point (NAP)
A major Internet connection point that allows organizations to interconnect and exchange information and traffic to flow from freely from ISP to ISP.

Network adapter
A device such as an Ethernet card that enables a computer to be attached to a network.

Network equipment building system (NEBS)
A requirement for central office equipment in the North American Public Switched Telephone Network. Originally developed by Bell Labs (now Telcordia) in the 1970s and released as a public document in 1985.

Network operations center (NOC)
The group responsible for the day-to-day care and feeding of a network. Also called a network control center (NCC).

Node
Transmission equipment placed in the outside plant to connect multiple users to a common link that extends back to a head end, CO, or similar location.

Noise
In a cable or circuit, any extraneous signal that tends to interfere with the signal normally present in or passing through the system.

Nonzero dispersion-shifted fiber (NZDS)
Single-mode fiber designed for DWDM and optical amplifier applications. Specified in ITU-T G.655.

Numerical aperture (NA)
A measure of the angular acceptance for a fiber, approximately the sine of the half-angle of the acceptance cone. The NA of an optical fiber defines a characteristic of the fiber in terms of its acceptance of incoming light. "Light gathering ability," and "acceptance cone" are all terms describing this characteristic.

Nylon
An abrasion-resistant thermoplastic with good chemical resistance.

O-band
The "original" transmission band, occupying the 1260 to 1360 nm wavelength range, with a center wavelength of 1310 nm. Used in FTTH standards for upstream transmission.

Occupational Safety & Health Administration (OSHA)
The main government agency for enforcement of safety and health law in the United States.

OM1
Legacy 62.5/125 multimode fiber designed for use with LEDs. Designated by IEC 11801.

OM2
Legacy 50/125 multimode fiber designed for use with LEDs. Designated by IEC 11801.

OM3
Laser-optimized 50/125 multimode fiber with an effective modal bandwidth of 2000 MHz-km. Designated by IEC 11801.

OM4
Laser-optimized 50/125 multimode fiber with bandwidth of 4,700 MHz-km. Standardized by IEC 11801.

Open system interconnection (OSI)
A seven-layered framework of standards for network communication. OSI creates an open systems networking environment where different systems can share data regardless of vendor or platform.

Operational support system (OSS)
Software that furnishes tools to provide network control, monitoring and business functions.

Operations, administration and maintenance (OAM)
A group of network management functions that provide fault indications, performance information, and network diagnosis.

Optical access networking (OAN)
An access network made up of optical transmission links as opposed to copper links composed of twisted-pair or coaxial cabling.

Optical add/drop multiplexer (OADM)
A multiplexer typically used in DWDM systems to allow a wavelength to be added or dropped optically. Can be fixed (FOADM), reconfigurable (ROADM), or dynamic (DOADM).

Optical amplifier
A device that amplifies light without converting it to electrical signal. Types include the EDFA, Raman, and SOA.

Optical attenuator
A passive component that produces controlled signal loss in an optical transmission line to decrease the optical power. Available as fixed or as variable types.

Optical carrier (OC)
Usually followed by a numerical designator such as 1, 12, 192, etc. Used in SONET and ATM transmission systems to describe the optical conversion of a synchronous transport signal at a specific rate, i.e., OC-3.

Optical circulator
A multiport device that steers optical energy between specific ports. Used in conjunction with a Bragg filter to provide OADM.

Optical density (OD)
Used with laser protective eye wear. Optical density is the BASE-10 logarithm by a factor of 1000.

Optical distribution network (ODN)
The fibers, splitters, couplers, etc., in a passive optical network that provide the optical transmission means from the OLT to the users, and vice versa.

Optical-electrical-optical (OEO)
Specifies a network switch that receives an optical signal, and demultiplexes, switches, multiplexes and re-transmits the signal optically. Can perform 3R functions.

Optical fiber
An optical waveguide comprised of a light-carrying core and cladding, which traps light in the core. Fiber optic communication systems use either single-mode or multimode types.

Optical filter
A passive component used to modify the optical radiation that passes through it, usually by altering the spectral distribution. Employed to reject or absorb optical radiation in particular ranges of wavelength while transmitting it in other ranges. Tunable optical filters have the ability to track the signal wavelength variation over its operating wavelength range while untunable models have fixed values.

Optical isolator (OI)
A nonreciprocal device intended to suppress backward reflections along an optical fiber transmission line while having minimum insertion loss in the forward direction.

Optical line terminal (OLT)
The PON controller card or unit located at the service provider. The laser at the OLT is frequently a DFB laser that transmits at 1490 nm or 1550 nm and is always on. Signals from the OLT tell the ONTs when to send upstream traffic to it. Several OLTs may be located in a single chassis.

Optical loss
The amount of optical power lost as light is transmitted through fiber, splices, couplers, etc. Also known as attenuation; measured in dB.

Optical loss test set (OLTS)
A single-mode or multimode test set consisting of a light source and power meter. OLTS is used for measuring a completed fiber optic cable assembly's loss (in dB) at the connector interfaces, within the specified wavelength of the fiber optic.

Optical network terminal (ONT)
A media converter or gateway in the home. The ONT located either inside or outside the home or business converts the signals from light to electrical signals and contains ports to distribute signals on the existing home wiring (or wirelessly).

Optical power
The amount of radiant energy per unit time, expressed linearly (watts) or logarithmically (dB).

Optical protection switch (OPS)
See *bypass switch.*

Optical receiver
An electronic device that converts optical signals to electrical signals.

Optical return loss (ORL)
The sum of the amount of light reflected from all optical fibers and components. The fiber, connectors, or splices in an optical system can cause the reflection.

Optical signal-to-noise ratio (OSNR)
The difference between the signal being transmitted and the noise being created by an optical laser's pulse. The higher the OSNR, the better the quality of service.

Optical supervisory channel (OSC)
A channel, accessed at each optical line amplifier site, used for maintenance purposes including but not limited to remote site alarm reporting, communications necessary for fault location, and orderwire. Not used to carry payload traffic.

Optical switch
A passive component possessing two or more ports that selectively transmits, redirects, or blocks optical power in an optical fiber transmission line.

Optical time-division multiplexing (OTDM)
Use of optical processors to multiplex, process, and demultiplex signals to achieve higher speeds. There are two fundamentally different types of OTDM, interleaved and slotted. OTDM may well be a practical necessity for generating data rates well above 40 Gb/s.

Optical time-domain reflectometer (OTDR)
A type of test equipment used to characterize a fiber via the transmission of an optical pulse. The resulting backscatter and reflections are measured as a function of time attenuation. The OTDR provides identification of defects over a length of fiber. Types include mainframe, full feature, mini, fault locators, and specialty OTDRs.

Optical-to-electrical (OE)
Shorthand notation for a point or device that converts an optical signal to an electrical signal.

Optical waveguide fiber
A high refractive index core with low refractive index cladding.

Optoelectronic
Pertaining to a device that responds to optical power, emits or modifies optical radiation, or utilizes optical radiation for its internal operation.

Optomechanical switch
Bipolar switch, based on moving fibers or mirrors, that moves optical signals between fibers.

OS1
G.652 single-mode fiber designation by IEC 11801.

OS2
G.652D single-mode fiber designation by IEC 11801.

Outlet
See *telecommunications outlet.*

Output power
Radiant power, expressed in watts.

Outside diameter (OD)
A measurement of the diameter of ferrules, cables, ducts, and innerducts, e.g., 2.5 mm.

Outside plant (OSP)
The portion of a communication network that exists mostly outdoors, but also between transmission sites. It includes patch panels, closures, pedestals, the media (e.g., fiber, twisted pair, coax) and the structure (aerial, underground, etc.) where the cable is installed and routed. The patch panels at each end are points of access for testing, as well as a point of separation of responsibilities for the transmission network.

Overbuild
Network deployment in an area that is served by an incumbent network operator. Although the services offered by the new provider may differ from those offered by the incumbent provider(s), some degree of competition is usually implicit.

Overfilled launch condition (OFLC)
When a light pulse floods the core of a fiber. Since LEDs produce erratic or incoherent burst of lights, they “overfill” the core when coupled to it.

Packet
A data unit of variable length used in communications protocols such as Ethernet and IP. Packets allow some flexibility by allowing more data to be sent without breaking it up into pieces and then re-assembling it at the receiver, in turn reducing overhead.

Packet switching
Messages are divided into small chunks that fit easily into memory and reassembled into the original message at the destination, enabling communications channels to be used simultaneously by more than one node.

Passive
A component that requires no electrical power to operate, i.e., optical splitters, wavelength division multiplexers, filters, circulators, and optical attenuators.

Passive dispersion compensator
A passive component used to compensate the chromatic dispersion of an optical path. Can use dispersion compensating fiber or Bragg filters.

Passive optical network (PON)
A point-to-multipoint system, specified by the ITU, IEEE, and SCTE, that is made up of fiber optic cabling, passive splitters and WDMs that distribute an optical signal from the service provider to homes (FTTH) or buildings (FTTB).

Patchcord
A fixed length of cable with like connectors on both ends (or, in the case of a hybrid cable, different connectors). Sometimes called a cable assembly, patch cable or jumper.

Patch panel
A wall or rack mounted cross-connect panel for interconnection of multiple cables or fibers.

Pathway
A facility for the placement of telecommunications cable.

Photodetector
An electro-optic device that transforms light energy into electrical energy.

Photodiode
A semiconductor that converts light into an electrical signal, used in fiber optic receivers.

Photon
The packet or element of light exhibiting features of both particle and wave.

Photonic integrated circuit (PIC)
A collection of photonic components monolithically integrated to perform a function.

Physical contact (PC)
Refers to the endface polish of a ferrule. Designed to lower reflections by changing the spherical or angle at the end of a ferrule and its internal fiber. Variations include PC, super PC (SPC), ultra PC (UPC), and angled PC (APC).

Pigtail
A short length of cable that has one end terminated with a connector. The pigtail is spliced to existing cable and placed into a splice tray in a patch panel. Pigtails are generally manufactured for single-mode fiber with machine polished endfaces for low backreflection.

PIN diode
Positive intrinsic negative diode, a type of photodiode used to convert optical signals in a receiver. Can be used with both analog and digital systems.

Pitting
An unacceptable polishing condition usually caused by the contamination of the lapping film from a combination of fiber optic and grit particles.

Plain old telephone service (POTS)
Basic telephone service, dial tone without special features.

Plastic-clad silica fiber
A fiber composed of a silica glass core with a transparent plastic cladding.

Plastic optical fiber (POF)
An optical fiber type in which both the core and cladding are made from plastic. Their transmission is typically much poorer than glass fiber, and their lowest losses are in the visible region. GI-POF is the high bandwidth version using a graded index core.

Plenum
Defined in the NEC as the air handling space between walls, under structural floors, and above suspended drop ceilings, which can be used to route intrabuilding cabling. See *OFNP*.

Plug
Connector. The male side of a connection. Usually consists of three main parts: the body, ferrule and strain relief boot.

Point of presence (POP)
The physical location where a long-distance carrier terminates lines before connecting to the local exchange company, another carrier, or directly to a customer.

Point-to-multipoint (P2MP)
A star topology with optical splitters for PON systems in which an OLT is optically linked to multiple ONTs through entirely passive means.

Point-to-point (P2P, PtP)
A topology in which all fiber links are from one transmitter to one receiver. Branching can be done at an intermediate point via an active device located anywhere on the network, including the CO or a curb-side enclosure. For FTTx installations, it is typically used in active Ethernet.

Polarization
The orientation of the electric and magnetic field vectors of a propagating electromagnetic wave. An electromagnetic wave theory describes in detail the propagation of optical signals (light).

Polarization mode dispersion (PMD)
Typical single-mode fibers support two perpendicular polarizations of the original transmitted signal, which may travel at different speeds and arrive at different times. The average difference in arrival times of the two polarization modes, normalized with length, is referred to as PMD.

Polarized dispersion loss (PDL)
The difference in dB between the maximum and minimum values of loss (attenuation) due to variation of the polarization states of light propagating through a device. The ITU defines PDL as polarization dependent loss, the maximum variation of insertion loss due to a variation of the state of polarization (SOP) over all SOPs.

Polishing paper
See *lapping film.*

Polishing puck
A fixture manufactured to hold the fiber optic connector ferrule perpendicular to a lapping film surface while polishing the fiber optic endface.

Polyethylene (PE)
A thermoplastic used to jacket aerial and direct buried cables.

Polypropylene
A thermoplastic similar to PE but stiffer and with a higher softening point (temperature).

Polyurethane (PU)
A thermoplastic material used in cable jackets derived from the polymerization of ethylene gas. Basically, they are pure hydrocarbon resins with excellent dielectric properties.

Polyvinyl chloride (PVC)
A general-purpose thermoplastic jacket material used in the manufacture of riser-rated cable and cordage.

Polyvinylidene fluoride (PVDF)
A dielectric fluoropolymer that is resistant to corrosive chemicals and radiation. Used to jacket stranded cable.

Potting
Sealing by filling with a substance to exclude moisture.

Power
The rate at which energy is absorbed, received, transmitted, transferred, etc., per unit time. Optical power is measured in dBm or watts.

Power budget
The difference (in dB) between the transmitted optical power (in dBm) and receiver sensitivity (in dBm).

Power meter
Test equipment that measures the optical power (dBm) and attenuation (dB) in a fiber optic connector, fiber optic cable, or fiber optic system.

Premises
Defined as the subscriber's home or place of business. In a multiple dwelling unit, each apartment is counted as one.

Private branch exchange (PBX)
Customer premises version of central office switch. Switches calls between phones on premises and provides a second dial tone for calls over the public network.

Profile alignment system (PAS)
A core alignment technique for fusion splices in which light is injected at right angles. A CCD camera detects the fiber's refractive inlet profile in the X and Y axes for optimization.

Profile dispersion
Difference between maximum refractive index in the core and maximum refractive index in the cladding.

Protocol
A standardized communications convention enabling the orderly and accurate transfer of data between stations.

Protrusion
According to the TIA, the fiber optic is either polished even with the endface or has a positive or negative protrusion, i.e., "sticks out" or is recessed.

Public switched telephone network (PSTN)
The traditional voice network infrastructure, including both local and long distance service, that has been in use in various parts of the world for the last century.

Pull point
A physical location where optical cable can be accessed and pulled, reducing friction and damage, and allowing for longer installed spans.

Pulling tension
The force that can be applied to a cable without affecting the specified characteristics for the cable, or the longitudinal force exerted on a cable during installation. Also known as pulling stress.

Pulse broadening
An increase in pulse duration resulting in optical dispersion.

Pulse code modulation (PCM)
A coding scheme for converting analog signals into a digital bit stream.

Pulse spreading
The dispersion of incoming optical signals along the length of an optical fiber.

Pulse width
A measurement of the full width half maximum (FWHM) value of a light source's peak power and spectral width at the 3 dB point. Lasers in OTDRs can change pulse width to create greater dynamic range.

Pulsed lasers
Lasers that emit energy in a series of short bursts, or pulses, and are inactive between each pulse. They typically deliver several watts of peak power per pulse.

Push/pull
Connector clip or locking device that holds the connector in a socket or interface. Uses a "push then pull" coupling technique. SC, LC, and MPO/MTP are common types of connectors using a push/pull coupling mechanism.

Quadplexer
Commonly known as a passive WDM, this transceiver package performs four multiplexing or demultiplexing functions. Used in 10 Gigabit OLTs when coexisting with legacy PON systems.

Quality of service (QoS)
A measure of the telephone service quality provided to a subscriber.

Raceway
A metal or plastic channel designed to hold and protect cables. Types include ladder, splice, and mesh trays. Fiber raceway systems are designed specifically for fiber optic cables.

Rack unit (RU)
A measurement of vertical space in an equipment rack. One rack unit is equal to 1.75 inches (4.45 cm).

Radio frequency interference (RFI)
The disruption of signals which can be caused by high voltage and lightning.

Radio frequency over glass (RFoG)
An SCTE 174 standard released in 2010, RFoG addresses PON network transmission for the CATV industry.

Radius
Half of the diameter of a circle measured from the center point.

Radius of curvature
Curvature of the endface measured from the side of the connector ferrule. Referenced in millimeters.

Raman fiber amplifier
These amplifiers use the Raman effect to transfer power from pump lasers to the amplified wavelengths.

Rayleigh scattering
The scattering of light into a direction generally reverse to the original one. The principle on which OTDRs operate; the scattering of light caused by index of refraction variations in the submicroscopic structure of the glass. One of the two major causes of attenuation in optical fibers.

Receive (Rx)
Refers to the detection of light from an optical source.

Receiver (RCVR)
An electronic unit that converts an optical signal to an electrical signal using an APD or PIN photodiode.

Receiver sensitivity
This tells how much optical power the photodetector must receive to achieve a specified base band performance, such as a specified bit error rate or signal-to-noise ratio. Expressed in dBm.

Receptacle
A connector adapter with an internal LED, laser or detector that connects to optical plug assemblies.

Reconfigurable OADM (ROADM)
Unlike OADMs, ROADMS can be managed via a network connection without need for a truck roll. They function as optical switches, allowing for remote service changes, and provide an express wavelength path and power monitoring.

Reference cables
Cables used as a reference for testing a fiber optic assembly on either an optical loss test set (OLTS) or an optical return loss (ORL) test set. Usually nulled or zeroed out to measure the loss of a fiber optic assembly.

Reflectance
The percentage of light reflected from a component, such as a connector, splice, splitter, or WDM.

Reflection
The abrupt change in direction of a light beam at an interface between two dissimilar media that returns the beam into the medium where it originated, i.e., a mirror.

Refraction
The bending of a beam of light in transmission between two dissimilar materials or in a graded index fiber where the refractive index is a continuous function of position.

Refractive index
The ratio of light velocity in a vacuum to its velocity in the transmitting medium.

Regional Bell operating company (RBOC)
A company formed from the forced breakup of AT&T and the Bell system.

Remote terminal (RT)
A POTS-related switching terminal that is remotely located in a pedestal or electronics cabinet.

Repeatability
The amount of times a connector can be mated within an interface before the amount of attenuation measured exceeds the Telcordia GR-20 standard.

Repeater/regenerator
A 3R repeater is a device inserted at intervals along a circuit that detects a weak signal, amplifies it, cleans it up, and retransmits it in optical form. A 3R regenerator is a receiver and transmitter combination used to reconstruct signals for digital transmission. Optical amplifiers are 2R regenerators.

Ribbon cable and fiber
A cable that has internal optical fiber ribbons. Up to 24 fibers (250 μm) are spaced evenly, sandwiched between two layers of matrix. Normally there are up to 12 fibers per ribbon.

Ribbon splice
A fusion or mechanical splice that aligns and fuses or mechanically bonds two ribbon fibers together. Ribbon splices require special stripping and cleaving tools.

Rights of way (ROW)
Legal right of passage over land owned by another.

Ring topology
A communications topology in which each station is logically arrayed in a ring and passes information to the next station in order.

Ripcord
An internal element placed under the cable jacket to assist the technician in stripping and removing cable jackets.

Rise time
The time required for the leading edge of a pulse to rise from 10% to 90% of its amplitude; the time required for a component to produce such a result.

Riser cable
Cable installed in vertical runs and penetrating more than one floor or cables installed in vertical runs in a shaft. Rated by the NEC/CEC for resisting flame spread and smoke generation.

Roll-off
An OTDR trace of a fiber that gradually rolls off due to nonreflective breaks.

Router
Highly intelligent devices that connect networks, typically supporting multiple protocols.

Safety data sheet (SDS)
Technical bulletin required by OSHA detailing information about the physical or health hazards of a chemical or mixture. Formerly known as MSDS.

Sag
The distance measured vertically from the fiber optic cable to the straight line joining two points of support. Unless otherwise stated, the sag referred to is at the mid-point of the span.

Sag section
A section of line between two dead-end structures. One or more of these may be present in a stringing section.

Sag span
A span selected within a sag section as a control to determine proper sag, and therefore tension of the optical cable. At least two and normally three sag spans per section are required to properly sag. This may increase where span lengths vary greatly or for hilly terrain.

Sag tension
The tension at which the fiber optic cable is designed to be installed. Usually at the initial sag.

S-band
The "short" DWDM transmission band, which occupies the 1460-1530 nm wavelength range.

SC connector
Subscriber connector, a push/pull connector recognized as the preferred optical fiber connector standard. It is available in simplex, duplex, hybrid, or hardened styles.

Scattering
Intrinsic fiber losses caused by undissolved particles, boundary roughness, and intrinsic material losses.

Scribe
When an optical fiber is slightly scratched and then broken (scribing) to achieve a 90° endface. For splicing, the scribe tool needs to cleave as close as possible without angles, chips, or cracks. These tools are more expensive than hand scribe tools used for connectorization, where the final polish will be performed by machine or hand.

Scribe tool
See *cleave tool.*

Self-healing ring (SHR)
A system architecture consisting of two counter-rotating directions for communications between nodes. In normal use, the data traffic is sent in both directions. In the event of a broken fiber in one of the fiber loops, the data will reach the affected remote device via the other fiber ring. In this way, data traffic can still travel to all surviving sections of the ring, even if the path is via a longer fiber route.

Sequential markings
Metric or footage designations located at periodic locations on the outer jacket of cables.

Service loop
(a) Slack in a splice tray, closure, or vault to accommodate future needs. (b) When a device is terminated to the wire in the communications outlet, a fair amount of "slack" should be left on the wire and wound in the box to accommodate future trimming when devices are changed out.

Serving area (SA)
An area defined by 32 optical network terminals (ONTs).

Sheath
See *cable jacket.*

Sheave
A wheel, complete with arm or frame, suspended from structures to permit stringing of fiber optic cables. The sheaves must be lined with urethane or neoprene and have a diameter as required in specifications for each type of cable being installed for normal vertical suspension points. For increased deflection angles, large diameter sheaves or multiple sheave assemblies are required.

Short wavelength
Considered 850 nm and lower in wavelength. Also covers the visible range (630-700 nm)

Signal-to-noise ratio (SNR)
The ratio of the power of the signal versus the power of the background noise, usually measured in decibels. Describes the quality of an electronic transmission system.

Silicon detector
A semiconductor that used absorbed photon energy to stimulate carriers from one energy level to a higher one. The change in charge across the junction is monitored as a current in the external photodiode circuit. Silicon photodetectors are commonly used in multimode systems operating at 850 nm.

Simple/signalling network management protocol (SNMP)
Network management architecture initially designed for the Internet but easily applied or extended to any network type.

Simplex
Operation of a communications channel in one direction only with no capability of reversing.

Simplex cable
A tight buffered breakout cable with only one fiber.

Single-longitudinal mode (SLM) laser
A laser, usually distributed feedback (DFB) type, where the spectral width is the width at the 20 dB down points divided by 6.07.

Single-mode
A step-index waveguide in which only one mode will propagate above the cutoff wavelength at a single wavelength.

Single-mode fiber (SMF)
A type of optical fiber specified by the ITU as G.652 (standard), G.652D (low water peak), G.657 (bend-insensitive), and G.655 (nonzero dispersion shifted). G.652 and G.652D fibers are also specified by the IEC 11801 standard as OS1 and OS2 fibers.

Sleeve
A mating device of either split or solid construction, commonly made of ceramic or bronze, that is used to align two ferrules within an adapter.

Small form factor (SFF)
A connector that offers higher density electronic equipment, enclosures, and distribution panels, lower connector costs, easier termination, and better optical performance.

Snell's Law
The principle of the angle of incidence when light passes through materials with differing refractive indices.

Source
Usually an LED or laser used to convert an electrical information-carrying signal into a corresponding optical signal for transmission by an optical fiber.

Spectral bandwidth
The difference between wavelengths at which the radiant intensity of illumination is half its peak intensity.

Spectral width
A full width half maximum (FWHM) measurement of a LED or laser light source to determine its optical width.

Speed of light
2.998×10^8 meters per second measured in a vacuum.

Splice
The mechanical or fusion means of joining two fibers together with a minimal loss and reflectance.

Splice closure
A cable and fiber management product that environmentally protects and houses optical splices. Available as inline or butt style, the closure is usually in a dome or clamshell configuration. Splice closures can also hold connectors and optical splitters. Telcordia GR-771 specifies mechanical requirements and environmental specifications and tests.

Splice organizer
A tray or other device used for the permanent storage of mechanical or fusion optical splices.

Splice panel
A rack or wall-mounted panel that allows cables to be organized and spliced. The panel holds splice trays, secures the cable, grounds any metallic members, and organizes and stores buffer tubes, fibers, and splices.

Splice protector
A device which is placed over the fusion splice to provide mechanical strength and protection to allow easy handling of the splice for organization in a splice tray or other storage. Two types are the heat shrink protector and the butterfly.

Splice tray
A protective tray that holds spliced fibers for slack and protection.

Splicing
Permanent joining of identical or similar fiber ends without a connector.

Splitter
A fiber device that optically splits signals. The splitters used in a PON outside plant network are optical splitters that distribute optical signals from the OLT into the ONTs. Splitters used in FTTx installations are specified by the ITU G.671 standard as wavelength independent couplers (WIC), which provide the same attenuation regardless of wavelength or direction.

ST connector
A straight tip, keyed bayonet with 2.5 mm ferrules. Available in ST I or ST II styles.

Stapler cleaver
Shaped similar to a stapler, its blade is made from a material sharp enough to nick the fiber optic and, by pressing down on a flexible tongue, cleaving the fiber optic. Most often used in a cleave and crimp style connector, and for acceptance testing.

Star
A topology for communications networks that involves transmission of data through a central location to other users.

Star coupler
An optical splitter in which many fibers have their signals mixed at a single optical element. The mixed signals are then transmitted back through all the fibers. The name comes from the geometrical arrangement; all fibers come together at a single point.

Star topology
Also known as a point-to-multipoint (P2MP) topology, the star topology has one hub that connects all users. In FTTH, all PON systems are star topologies. Variations include the distributed star topology, which has two or more splitters cascaded from a single port.

Step-index fiber
A type of fiber where the refractive index of the core is uniformly higher than that of the surrounding cladding.

Storage area network (SAN)
A network which links host computers to storage servers and systems.

Strain relief
How a cable's physical load is attached and addressed at the rear of a connector. In fiber optic cable assemblies using a 3-mm cordage, the aramid yarn is epoxied or crimped to provide the strongest level of strain relief while protecting the cable's internal optical fiber(s).

Stranded cable
In stranded cables, individual color-coded buffer tubes are wrapped or "stranded" around the cable's central strength member.

Stripper
Mechanical tool used to remove buffer coatings from fibers.

Subminiature type A (SMA) connector
A nonkeyed, noncontacting, multimode threaded connector borrowed from the coax industry. Types include 905, 906, or optimate.

Subscriber line interface circuit (SLIC)
The line card that provides the interface between local loop and telco switching equipment.

Super physical contact (SPC)
The spherical endface polish of a ferrule and fiber that is performed on a polishing machine. Typically 50 dB return loss. Superseded by the UPC polish.

Surface-emitting LED (SLED)
A diode that emits light perpendicular to the semiconductor chip. Most LEDs used in data communications are surface emitting.

Switch
A device for re-routing signals from one optical fiber into others. Types include MEMs, matrix, bypass, optical cross-connect, and electrical network switches.

Swivel
Installation hardware used to eliminate winding and tangling of cables during installations.

Synchronous digital hierarchy (SDH)
A worldwide, high-speed synchronous protocol standard transmitting at up to 10 Gb/s. Known as SONET in North America.

Synchronous optical network (SONET)
ANSI-standard physical interface defined by its optical line rates known as optical carrier (OC) signals, frame format and OAM&P protocol. Adopted by the ITU as SDH.

Synchronous transfer mode (STM)
A transport and switching method that depends on information occurring in regular and fixed patterns with respect to a reference such as a frame pattern.

Synchronous transmission
A transmission method in which data characters are synchronized by timing signals generated at sending and receiving stations (as opposed to start/stop communications). Both stations operate continuously at the same frequency and are maintained in a desired phase relationship. Several codes may be used as long as they utilize the required line control characters. Also called "bi-sync" or "binary synchronous."

Synchronous transport signaling (STS)
The transmission speed of a SONET transmission medium, e.g., OC-48.

System margin
See *margin.*

T1
A North American data exchange protocol for constant bit rate systems. It operates at 1.544 Mb/s and can handle up to 24 telephone calls or other data. The corresponding European protocol E1 operates at 2.048 Mb/s and handles up to 30 telephone calls or other data.

T3
A faster implementation of T1. Using coaxial cable, T3 allows for data transmission rates of 45 Mb/s and is used for WAN backbones, the Internet backbone and connections from Internet service providers to the Internet backbone.

Take rate
Subscribers divided by homes connected. Expressed as a percentage, it can also be based on each type of service, i.e., take rates for data, video, voice, or triple/quadruple services.

Tap
A coupler in which part of the light carried by one fiber is split off and inserted into another fiber. Essentially the same as a Tee coupler. An example would be a 10/90% optical splitter.

TCP/IP
Transport control protocol/Internet protocol. Originally developed by the U.S. government, this product is the de facto standard for Internet and inter-network communications.

Tee coupler
A fiber optic coupler in which three fiber ends are joined together, and a signal transmitted from one fiber is split between the other two.

Teflon®
DuPont trademark for fluorocarbon resins.

Telcordia Technologies (Bellcore)
Formerly known as Telcordia-Bell Communications Research, it is the unofficial standards development body providing technical specifications for the RBOCs.

Telecommunications closet (TC)
An enclosed, secure space that houses telecom equipment, cable terminations, and cross-connects. Recognized for backbone and horizontal cable facilities.

Telecommunications Industry Association (TIA)
An organization that participates in setting standards.

Telecommunications outlet (TO)
A single-piece cable termination assembly (typically on the floor or in the wall) that contains one or more modular telecom jacks, e.g., RJs, coaxial terminators, fiber optic connections. If more than one type of connector is used, it is called a multiuser telecommunications outlet assembly (MUTOA).

Telecommunications space
The area where telecommunications equipment and cable are housed, installed, and terminated; e.g., work areas, telecommunications closets, and handholes.

Tensile strength
The pull stress that is required to break a given specimen.

Termination
Connection.

Termination tools
Tools used in preparing optical fibers for splicing and/or installation of connectors.

Terminator
An optical plug with the fiber dead ended so that there is no reflectance. Terminators measure component reflectance using the OTDR and also reduce Fresnel reflections at open connector ports.

Thermal rating
The temperature range in which a material will perform its function without undue degradation.

Thermoelectric cooler (TEC)
A device used in laser transmitters to maintain a cool, stable temperature for a laser diode prolonging its life, maintaining stable output power, and promoting wavelength stability.

Thermoplastic
A material that will soften, flow, or distort appreciably when subject to sufficient heat and pressure, i.e., PVC or PE.

Threshold
A defined pass or fail value, i.e., the maximum or minimum value of insertion loss in dB or dBm.

Tight buffered cable
A type of cable with internal 900-micron coated fibers, such as breakout and distribution styles. Jacket materials vary but they are normally rated for indoor use to meet plenum, riser, and LSZH requirements.

Tightly-coupled mode
A low order or axial mode from either a laser or a LED. Low order modes cause less differential mode delay (higher bandwidth).

Time division multiple access (TDMA)
A data transmission method in which a number of individual transmitters in different locations share a transmission channel, each occupying the channel for a portion of the total time.

Time division multiplexing (TDM)
A digital technique for combining two or more signals into a single stream of data by sharing time.

Topology
Physical and logical layout of a network.

Total internal reflection
100% reflection and 0% transmission of light at the interface of two optical media.

Transmitter
An electronic unit that converts an electrical signal to an optical signal using LEDs or lasers.

Triple play
Voice, video, and data communications.

Triplexer
Commonly known as a passive WDM, this transceiver package performs three multiplexing or demultiplexing functions.

Trunk
A single circuit between two switching centers and/or individual distribution points.

Tunable laser
A laser that can change its wavelength. Applications include research, OTDRs, and for protection in transmission systems.

Twisted pair
Cable with at least two insulated wires intertwined to reduce electromagnetic interference.

U-band
The “ultra long” DWDM transmission band, occupying the 1625-1675 nm wavelength range.

Ultra physical contact (UPC)
The spherical endface polish of a ferrule and fiber that is performed on a polishing machine to reduce reflections. Typically 55 dB return loss.

Undercut
According to Telecommunications Industry of America (TIA), a negative protrusion where the fiber optic is lower than the endface of the connector within the ferrule.

Underfilled launch condition (ULC)
When a laser diode in a Gigabit transmission system only fills a small percentage of the fiber core.

Underwriter’s Laboratory (UL)
A nonprofit laboratory which examines and tests devices, materials and systems for safety, not for satisfactory operation.

Uninterruptible power supply (UPS)
An auxiliary power unit providing continuous power to a telephone system in case commercial power is lost.

Unitube cable
This type of cable has a large central tube in which the fibers are grouped using color-coded binder thread. Unitube cables are physically smaller than stranded-type cables. Also known as central tube or LXE cable.

User network interface (UNI)
The user end of an access network, similar to an ONU but not necessarily optical.

UV adhesive
Ultraviolet adhesive hardened by the use of ultraviolet radiation. Normally date coded.

UV connectors
Connectors manufactured with a clear body and ferrule to allow the curing of ultraviolet adhesive, bonding the fiber optic inside the ferrule.

Vapor axial deposition (VAD)
A method of optical fiber manufacturing where a the end of a bait rod is used to grow a preform of oxidized soot.

Variable optical attenuator (VOA)
A fiber system attenuator with adjustable attenuation; often used to test system performance by increasing attenuation until the system fails.

Vault
Storage product allowing for excess cable slack and splice case.

Vertical-cavity surface-emitting laser (VCSEL)
A high-speed, low-cost laser operating at the 850-nm wavelength that is used for applications such as Gigabit Ethernet where the modulation rate of current LEDs is insufficient

Video on demand
A video service that allows users to select a program and begin viewing it at any time. It can allow VCR-like playback control.

Video over IP
The transmission of video programming over an IP network. If the source programming is digital, it is encapsulated into IP packets. Otherwise, it is digitized and usually compressed. It can then be converted back to analog by equipment at the customer's premises or viewed on a digital television.

Visible light
Electromagnetic wavelengths, ranging from 380-770 nm, that are visible to the human eye.

Voice over IP (VoIP)
The transmission of telephone calls over an IP network.

Water migration
The act of water traveling through a breach in the outer jacket(s) of a telecommunications cable, moving along the conductors due to capillary action. A corrosive action as the water reacts with the insulator and/or conductor.

Watts (W)
A linear measure of optical power, usually expressed in milliwatts (mW), microwatts (μW), or nanowatts (nW).

Waveguide
An older term for optical fiber; a dielectric material structure able to support and propagate modes.

Waveguide dispersion
Dispersion caused by the difference in the speed of light of the core and the cladding in single-mode fibers. Waveguide dispersion also changes with wavelength as the size of the mode field diameters increases with wavelength.

Wavelength
The optical term for frequency. Fiber optics generally uses the 850 nm, 1300/1310 nm, 1550 nm and 1625 nm wavelengths for transmission purpose due to the marriage of performance with light sources, optical fibers, and optical detector technologies.

Wavelength division multiplexing (WDM)
The combining of two or more optical signals for transmission over a common optical path, usually a single fiber. WDM devices have a channel wavelength spacing greater than or equal to 50 nm. They typically separate a channel in one conventional transmission window (e.g., 1310 nm) from another (e.g., 1550 nm). Types include wide WDM, coarse WDM, and dense WDM.

Wavelength independent coupler (WIC)
Defined in ITU G.671 as an optical splitter that provides the same attenuation regardless of wavelength or direction.

Wavelength selectable switch (WSS)
A type of ROADM used in DWDM networks to allow a network operator to change the direction of an added or dropped wavelength through the use of mirrors mounted on micro-electrical-mechanical positioners.

WDM coupler
A passive device designed to either (a) optimally combine light of multiple predetermined wavelengths into a single core; or (b) optimally sort and segment those wavelengths and couple them separately into output fiber cores.

WDM-PON
Defined by FSAN as a next generation (NG2) network in which each subscriber is assigned their own wavelength.

White light
A mixture of colors of visible light that appears white to the eye. In theory, a mixture of three colors is sufficient to produce white light.

Wide area network (WAN)
An integrated data network linking metropolitan or local networks over common carrier facilities.

Work area (WA)
A building space where the occupants may interact with telecommunications terminal equipment (computers, faxes, phones, etc.). A media or telecommunications outlet would be used here for duplex fiber terminations or, in the case of multiple users, a MUTOA outlet.

Yield
The percentage of completed splices or assemblies that pass specifications and are good the first time. The higher the yield (e.g., 95%), the greater the installed cost benefit.

Zipcord
A separable, two-fiber, breakout-style cable with a diameter (per buffer) of 1.6 mm (mini Zipcord), 2.5 mm, or 3.0 mm (standard cable assembly cordage).

Acronyms

ABF Air blown fiber.

ADM Add/drop multiplexer.

ADSL Asymmetric digital subscriber line.

ADSS All-dielectric self-supporting.

AM Amplitude modulation.

ANSI American National Standards Institute.

AOC Active optical cable.

AON All-optical network.

APC Angled physical contact.

APD Avalanche photodiode.

APL Allowable path loss.

APON Asynchronous transfer mode PON.

APS Automatic protection switching.

APVD Advanced plasma and vapor deposition.

ASE Amplified spontaneous emission.

ASOF Application-specific optical fibers.

ASQ American Society for Quality.

ATE Automatic test equipment.

ATM Asynchronous transfer mode.

AWG Arrayed waveguide grating.

BER Bit error rate.

BERT Bit error rate tester.

BFOC Bayonet fiber-optic connector.

BIF Bend-insensitive fiber.

BI-MMF Bend-insensitive multimode fiber.

B-ISDN Broadband ISDN.

BLEC Building local exchange carrier.

B-PON Broadband passive optical network.

CAP Competitive access provider.

CATV Community antenna television.

CCTV Closed circuit television.

CD Chromatic dispersion.

CEC Canadian Electrical Code.

CEV Controlled environmental vault.

CFP 100G form factor pluggable.

CIL Channel insertion loss.

CIR Cable index of refraction.

CLEC Competitive local exchange carrier.

CNR Carrier-to-noise ratio.

CO Central office.

CODEC Coder/decoder.

CORD Center for Occupational Research and Development.

CPE Customer premises equipment.

CSA Canadian Standards Organization.

CSF Cutoff shifted fiber.

CSM Central strength member.

CSMA/CD Carrier sense multiple access / collision detection.

CSO Composite second order.

CSRZ Carrier suppressed return-to-zero.

CTB Composite triple beat.

CW Center wavelength; continuous wave.

CWDM Coarse wavelength division multiplexing.

dB Decibel.

DBFA Dual-band fiber amplifier.

dBm Decibels relative to one milliwatt.

DCC Data communication channel.

DCE Data communications equipment.

DCF Dispersion-compensating fiber.

DCIM Data center infrastructure management.

DCM Dispersion compensation module.

DFB Distributed feedback (laser).

DGD Differential group delay.

DGE Dynamic gain equalizer.

DIB Dual-insulated buffer.

DIP Dual inline package.

DMD Differential mode delay.

DML Directly-modulated laser.

DOCSIS Data-Over-Cable-Service Interface Specification.

DOP Degree of polarization.

DOPL Differential optical path loss.

DP-QPSK Dual polarization quadrature phase-shift keying.

DPSK Differential phase-shift keying.

DPSS Diode-pumped solid-state.

DQPSK Differential quadrature phase-shift keying.

DS-*x* Digital signal (level).

DSF Dispersion-shifted fiber.

DSL Digital subscriber line.

DSP Digital signal processing.

DTE Data terminal equipment.

DWDM Dense wavelength division multiplexing.

ECMA European Computer Manufacturers Association.

EDA Equipment distribution area.

EDFA Erbium-doped fiber amplifier.

EF Encircled flux.

EFM Ethernet in the first mile.

EIA Electronic Industries Alliance.

ELED Edge-emitting diode.

EMB Effective modal bandwidth.

EMD Equilibrium modal distribution.

EMI Electromagnetic interference.

EMP Electromagnetic pulse.

EO Electrical–optical.

EPON Ethernet passive optical network.

ERK Emergency restoration kit.

ESCON Enterprise System Connection.

ESL Estimated splice loss.

ETSI European Telecommunications Standards Institute.

EVC Equivalent voice channels.

FAT Fiber access terminal.

FBG Fiber Bragg grating.

FBT Fused biconical taper.

FC Fiber connector.

FCIA Fibre Channel Industry Association.

FDB Fiber demarcation box.

FDDI Fiber distributed data interface.

FDF Fiber distribution frame.

FDH Fiber distribution hub.

FDM Frequency division multiplexing.

FDU Fiber distribution unit.

FEC Fiber entrance cabinet; forward error correction.

FET Field effect transistor.

FIFM Fiber in the first mile.

FILM Fiber in the last mile.

FITL Fiber in the loop.

FM Frequency modulation.

FOCIS Fiber Optic Connector Intermateability Standard.

FOCS Fiber optic communication system.

FORJ Fiber optic rotating joint.

FOTP Fiber optic test procedure.

FOTR Fiber optic transceiver.

FOTS Fiber optic transmission system.

FP Fabry-Perot (laser).

FRP Fiberglass rodent protection.

FSAN Full Service Access Network.

FSWDM Full spectrum wavelength division multiplexing.

FTTA Fiber to the antenna.

FTTB Fiber to the building or business.

FTTC Fiber to the curb or cabinet.

FTTD Fiber to the desk.

FTTH Fiber to the home.

FTTN Fiber to the node.

FTTO Fiber to the office.

FTTx Fiber to the premises.

FWHM Full width, half maximum.

FWM Four wave mixing.

GbE Gigabit Ethernet.

GBIC Gigabit interface converter.

GD Group delay.

GEM G-PON encapsulation method.

GFF Gain flattening filter.

GI-MMF Graded-index multimode fiber.

GI-POF Graded-index plastic optical fiber.

G-PON Gigabit PON.

GRIN Gradient index.

HASB High air-speed blown.

HC Horizontal cross-connect.

HDA Horizontal distribution area.

HDPE High-density polyethylene.

HDSL High bit rate digital subscriber line.

HDTV High definition television.

HFC Hybrid fiber coax.

HFOC Hardened fiber-optic connector.

HIPPI High performance parallel interface.

HMFOC Hardened multifiber optical connector.

HSTR High-speed Token Ring.

HVAD Hybrid vapor axial deposition.

IC Integrated circuit; or intermediate cross-connect.

ICCF Interexchange Carrier Compatibility Forum.

ICEA Insulated Cable Engineers Association.

IDF Intermediate distribution frame.

IEC International Electrotechnical Commission.

IEEE Institute of Electrical and Electronics Engineers.

IFC Intrafiber cabling.

ILD Injection laser diode.

ILEC Incumbent local exchange carrier.

ILTA Integrable tunable laser assemblies.

InGaAsP Indium gallium arsenide phosphide.

IP Internet protocol.

IPA Isopropyl alcohol.

IPTV Internet protocol television.

IOR Index of refraction.

ISDN Integrated services digital network

ISI Intersymbol interference.

ISO International Standards Organization.

ISP Internet service provider.

ITS Information transport system; intelligent transportation system.

ITU International Telecommunications Union.

IVD Inside vapor deposition.

IXC Interexchange carrier.

kpsi Thousand pounds per square inch.

LAN Local area network.

LATA Local access and transport area.

LEC Local exchange carrier.

LED Light-emitting diode.

LIA Laser Institute of America.

LID Local injection and detection.

LSA Least square approximation.

LSZH Low smoke zero halogen.

LTGF Loose tube gel filled.

LWP Low water peak.

MAN Metropolitan area network.

Mb Megabit.

MC Main cross-connect.

MCPC Mode conditioning patchcord.

MCVD Modified chemical vapor deposition.

MDA Main distribution area.

MDF Main distribution frame.

MDPE Medium-density polyethylene.

MDU Multiple dwelling unit.

MEM Micro-electro-mechanical.

MFD Mode-field diameter.

MFU Multiple family unit.

minEMBc Minimum calculated effective modal bandwidth.

MiniBNC Miniature bayonet Neill-Concelman.

MLM Multilongitudinal mode.

MMF Multimode fiber.

MPD Mode power distribution.

MPEG Moving Pictures Experts Group.

MPLS Multiprotocol label switching.

MPLS-TP MPLS transport profile.

MPO Multifiber push-on connector.

MRCL Maximum rated cable load.

MSO Multiple system operator.

MSP Managed service provider.

MST Multifiber service terminal.

MSTP Multiservice transport platform.

MTBF Mean time between failures.

MTDC Multitenant data center.

MTP Multiple transfer push-on.

MT-RJ Mechanical transfer registered jack.

MTU Multiple tenant unit.

MUTOA Multiuser telecommunications outlet assembly.

NA Numerical aperture.

NAP Network access point.

NCC Network control center.

NEBS Network equipment building system.

NEC National Electrical Code.

NECA National Electrical Contractors Association.

NEMA National Electrical Manufacturers Association.

NESC National Electrical Safety Code.

NFPA National Fire Protection Association.

NGI Next generation Internet.

NIST National Institute of Standards and Technology.

nm Nanometer.

NOC Network operations center.

NRZ Nonreturn to zero.

ns Nanosecond.

NTIS National Technical Information Service.

NTSC National Television Standards Committee.

NZDS Nonzero dispersion-shifted fiber.

OA Optical amplifier.

OADM Optical add/drop multiplexer.

OAM Operations, administration and maintenance.

OAM&P Operations, administration, maintenance and provisioning.

OAN Optical access networking.

OC Optical carrier.

OCDMA Optical code division multiple access.

OD Outside diameter; optical density.

ODN Optical distribution network.

ODU Optical demultiplexer unit.

OE Optical-to-electrical.

OEE Optical entrance enclosure.

OEIC Optoelectronic integrated circuit.

OEO Optical–electrical–optical.

OFCP Optical fiber conductive plenum.

OFCR Optical fiber conductive riser.

OFDM Optical frequency division multiplexing.

OFL Overfilled launch.

OFLC Overfilled launch condition.

OFNP Optical fiber nonconductive plenum.

OFNR Optical fiber nonconductive riser.

OFSTP Optical fiber system test procedures.

OI Optical isolator.

OLS Optical line system.

OLT Optical line terminal.

OLTS Optical loss test set.

OM Optical multimode.

OMU Optical multiplexer unit.

ONT Optical network terminal.

ONU Optical network unit.

OOK On-off keying.

OOO Optical–optical–optical.

OPGW Optical power ground wire.

OPM Optical power meter.

OPS Optical protection switch.

ORL Optical return loss.

OS Optical single-mode.

OSA Optical spectrum analyzer; optical subassembly; Optical Society of America.

OSC Optical supervisory channel.

OSHA Occupational Safety and Health Administration.

OSI Open system interconnection.

OSNR Optical signal-to-noise ratio.

OSP Outside plant.

OSS Operational support system.

OTDM Optical time-division multiplexing.

OTDR Optical time-domain reflectometer.

OTN Optical transport network.

OTU Optical translator unit.

OVD Outside vapor deposition.

OXC Optical cross-connect.

P2MP Point-to-multipoint.

P2P Point-to-point.

PAS Profile alignment system.

PBX Private branch exchange.

PC Physical contact.

PCM Pulse code modulation.

PCVD Plasma chemical vapor deposition.

PDC Polarization dependence of the center wavelength.

PDFA Praseodymium-doped fiber amplifier.

PDL Polarized dispersion loss.

PDLC Polarization-dependent loss compensation.

PDM Polarization division multiplexing.

PE Polyethylene.

PIC Photonic integrated circuit.

PIN Positive-intrinsic-negative.

PIN-FET Positive-intrinsic-negative field-effect transistor.

PLC Planar lightwave circuit.

PLOAM Physical layer operations, administration, and maintenance.

PMD Polarization mode dispersion.

PMDC Polarization mode dispersion compensation.

PM-QPSK Polarization multiplexed quadrature phase-shift keying.

POF Plastic optical fiber.

PON Passive optical network.

POP Point of presence.

POTP Passive optical transport platform.

POTS Plain old telephone service.

PPE Personal protective equipment.

PSK Phase-shift keying.

PSTN Public switched telephone network.

PtP Point-to-point.

PTZ Pan, tilt, zoom.

PU Polyurethane.

PVC Polyvinyl chloride; permanent virtual circuit.

PVDF Polyvinylidene fluoride.

PXC Photonic cross-connect.

QAM Quadrature amplitude modulation.

QDM Double-band amplitude modulation.

QoS Quality of service.

QPSK Quadrature phase-shift keying.

RADSL Rate adaptive digital subscriber line.

RBOC Regional Bell operating company.

RBS Rated breaking strength.

RCVR Receiver.

RF Radio frequency.

RFI Radio frequency interference.

RFoG Radio frequency over glass.

RFTS Remote fiber test system.

RIN Relative intensity noise.

RML Restricted mode launch.

ROADM Reconfigurable optical add/drop multiplexer.

ROSA Receiver optical subassembly.

ROW Rights of way.

RT Remote terminal.

RTM Reference test method.

RTU Remote test unit.

RU Rack unit.

Rx Receive; receiver.

SA Serving area.

SAN Storage area network.

SBS Stimulated Brillouin scattering.

SCTE Society of Cable Telecommunications Engineers.

SDH Synchronous digital hierarchy.

SDM Spatial division multiplexing.

SDS Safety data sheet.

SDSL Symmetric digital subscriber line.

SDV Switched digital video.

SERDES Serializer/deserializer.

SFF Small form factor.

SFP Small form factor pluggable.

SHR Self-healing ring.

SLED Surface-emitting LED.

SLIC Subscriber line interface circuit.

SLM Single longitudinal mode (laser).

SMA Subminiature type A connector.

SMDS Switched multimegabit data service.

SMF Single-mode fiber.

SNMP Simple (or signalling) network management protocol.

SNR Signal-to-noise ratio.

SOA Semiconductor optical amplifier.

SONET Synchronous optical network.

SOP State of polarization.

SPC Super physical contact.

SPIE Society of Photographic Instrumentation Engineers.

SPM Self phase modulation.

SSB Single side band.

STM Synchronous transfer mode.

STP Shielded twisted pair.

STS Synchronous transport signaling.

SVC Switched virtual circuit.

SVOD Switched video on demand.

SWDM Short wavelength division multiplexing.

TAXI Transparent asynchronous transmitter receiver interface.

TC Telecommunications closet.

TCP/IP Transport control protocol/Internet protocol.

TDM Time division multiplexing.

TDMA Time division multiple access.

TEC Thermoelectric cooler.

TIA Telecommunications Industry Association.

TMC Traffic management center.

TO Telecommunications outlet.

TOSA Transmitter optical subassembly.

TPON Telephony passive optical network.

Tx Transmit; transmitter.

TTL Transistor-transistor logic.

UHDTV Ultra high definition television.

UL Underwriters Laboratory.

ULC Underfilled launch condition.

UNI User network interface.

UPC Ultra physical contact.

UPS Uninterruptible power supply.

UTP Unshielded twisted pair.

UV Ultraviolet.

VAD Vapor axial deposition.

VCSEL Vertical-cavity surface-emitting laser.

VFC Voice frequency channels.

VOA Variable optical attenuator.

VOD Video on demand.

VoIP Voice over Internet protocol.

VPN Virtual private network.

VPON Video passive optical network.

VSB Vestigial sideband.

VT Virtual tributary.

WA Work area.

WAN Wide area network.

WBMMF Wideband multimode fiber.

WDM Wavelength division multiplexing.

WHMIS Workplace Hazardous Material Information System.

WIC Wavelength independent coupler.

WSS Wavelength selectable switch.

WXC Wavelength cross-connect.

XFP 10 Gigabit small form factor pluggable.

XMD 10 Gb/s miniature device.

XPM Cross phase modulation.

ZDA Zone distribution area.

ZWP Zero water peak.