Chapter 1
Principles of Transmission

Chapter 1 provides the main concepts related to signal transmission through metallic and optical fiber transmission media. Among those concepts, this chapter discusses types of signals and their transmission, the composition and performance of different types of transmission media used within information and communications technology (ICT) systems, and termination hardware commonly used for ICT cabling.

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Principles of Transmission

Introduction

This chapter discusses the transmission of information over various physical media. It also identifies the impact that information and communications technology (ICT) systems cabling installation methods have on the transmission of information.

In the context of this manual, transmission is the movement of information by electromagnetic energy in the form of electrical or optical signals from one point to another through a transport medium (e.g., air, balanced twisted-pairs, optical fiber strands). This chapter deals with the use of metallic (e.g., copper) conductors and optical fiber (e.g., glass) strands for the transmission of signals in analog or digital form.

Three transmission methods are:

- Simplex—transmits signals in one direction only. A public address system is an example of simplex transmission. The signal, or the speaker's voice, is carried to a number of loudspeakers. The listener has no path to respond.
- Half-duplex—transmits signals in either direction but in only one direction at a time. This type of transmission typically requires agreement between stations and involves a push-to-talk switch arrangement on voice circuits or a signaling protocol on data circuits. A two-way radio or an intercom system is an example of half-duplex transmission.
- Full duplex—transmits signals in both directions at the same time. All telephone circuits are full duplex, allowing both parties to talk simultaneously.

The choice of a specific transport medium is influenced by economics and technical considerations such as the:

- Physical construction (e.g., diameter, conductor size, pair/strand count) characteristics of the cable.
- Type of services to be provided (e.g., voice, data, video).
- Topology and size of the network.
- Transmission path distance.
- Transmission performance characteristics of the cabling.

Electromagnetic interference (EMI) conditions can affect transmission in systems using metallic media. In balanced twisted-pair cabling systems, when the adverse effects of EMI conditions cannot be remedied by shielded cabling or by increasing the physical separation between the cabling and the source of problematic EMI, it may be necessary to place unshielded cabling in a shielded pathway (e.g., metallic conduit). In some cases, the use of optical fiber cabling instead of balanced twisted-pair cabling may be necessary.

Introduction, continued

All balanced twisted-pair cable, coaxial cable, and optical fiber media feature certain transmission characteristics that limit or define their respective performance capabilities. Therefore, media selection may be based on specific network requirements when such network requirements are known.

For balanced twisted-pair cabling, the assignment of a category or classification performance rating (e.g., category 5e/class D, category 6_A/class E_A) provides a simple means to select cabling suitable for the applications intended to be supported.

Twisted-pair cable is called balanced cable because the physical construction of both conductors and the associated connections to equipment at the cable terminations transmit information electrically at the same potential referenced to ground. Coaxial cable is unbalanced because the two conductors and the associated connections to equipment at the cable terminations transmit information electrically at different potentials referenced to ground.

Terminology

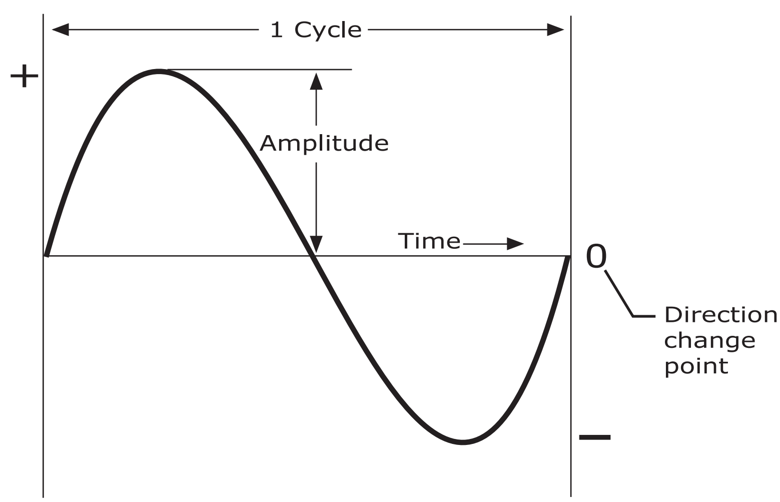
This section defines the major terms associated with signal transmission.

Alternating Current (ac) and Direct Current (dc)

The standard commercial and residential main power frequency differs, depending on the region. The two standard frequencies are 60 hertz (Hz [cycles per second]) and 50 Hz. Generally, 60 Hz can be attributed to North America and 50 Hz to many other regions of the world. Always verify the standard frequency within the region for which the installation is being performed.

For each sine wave in alternating current (ac), the voltage begins at the zero level and increases to its maximum positive value before dropping back to the zero level where the voltage becomes negative. The voltage continues to track in the negative level to reach a maximum negative value; it then becomes less negative until it reaches the zero level again and completes the cycle (see Figure 1.1). Although the voltage has gone to zero twice in each cycle, the eyes cannot perceive the rapid increase and decrease of the voltage.

Figure 1.1
Analog sine wave



Direct current (dc) refers to a steady value that does not change the polarity of the voltage or the direction of the current. It rises to its maximum value when switched on and remains there until the circuit is interrupted. A battery is an example of a dc source.

Terminology, continued

Electromagnetics

All electrical activity produces electric and magnetic fields. When electrical and magnetic fields intersect near or within a conductor, the energy of the field can transfer or couple onto the conductor. While this coupling can be desirable, for example, in the use of wireless charging, unwanted coupling, termed electromagnetic inference or EMI, can cause problems, including signal corruption, component malfunction, equipment failure, property damage, injury to personnel, and loss of life in the case of extreme exposure.

The subjects of EMI are complex. In ICT systems, the source of EMI can be external or internal to the cable.

External to the Cable

- Other cables (alien crosstalk [AXT])
- Motors
- Fluorescent lighting
- Switching power supplies
- Powered radio equipment and antennas

Internal to the Cable

- From another pair within the sheath (crosstalk)
- From the cable's shield, screen, or other metallic component that is improperly bonded and grounded

It is important to distinguish between EMI caused by ac circuit conductors or equipment (e.g., transformers) being improperly separated (high current) and fields caused by grounded conductors being needlessly paralleled (net current). Although the fields from a high-current conductor are fundamentally identical to those from a net current wiring error, the available mitigation strategies are quite different. Net current fields weaken directly with distance, whereas high-current fields weaken with the cube of the distance (fast). Shielding is ineffective for net current fields but is effective for high-current fields.

However, in most cases involving ICT systems cabling and pathways infrastructure, the adverse effects of EMI can be minimized effectively with appropriate cabling system component selection and proper installation procedures.

Terminology, continued

Frequency

Frequency is defined as the number of cycles a signal is repeated in a given time period. Typically, an ac signal is shown as a sine wave (see Figure 1.1). If the unit of time is equal to 1 second (s), the frequency is stated as 1 Hz.

The following are frequency unit sizes and names:

- 1 cycle in 1 s = 1 Hz
- 60 cycles in 1 s = 60 Hz
- 1000 cycles in 1 s = 1 kilohertz (kHz)
- 1 million (1,000,000) cycles in 1 s = 1 megahertz (MHz)
- 1 billion (1,000,000,000) cycles in 1 s = 1 gigahertz (GHz)
- 1 trillion (1,000,000,000,000) cycles in 1 s = 1 terahertz (THz)

Although humans can hear frequencies that range from 20 Hz to 20,000 Hz, typical voice-grade transmission of speech is generally limited to between 300 Hz to 3400 Hz, which covers the majority of the spoken voice range under normal conversational conditions.

Power, Current, and Voltage

Electrical power (P) measured in watts (W) has two variations also known as apparent or reactive power and true (real) power. When measured in conjunction with a time element (e.g., seconds, hours), this power applies to the energy consumed by an electrical device (e.g., motor, amplifier, telephone transmitter) over a period of time and typically is measured in kilowatt hours (kWh). Power is derived from electrical pressure measured in volts (V) and electrical current measured in amperes (A). Using a water analogy, voltage may be thought of as the water pressure while current represents the quantity of water delivered. A power source having voltage without current flow will not provide any power and, therefore, will not energize a device to perform the desired function.

Apparent power is a characteristic of ac electrical circuits that have reactive components (inductors such as transformers and capacitors). Because of these components and their effects on ac current flow, the measured power value may be greater than the actual power consumed by the connected load and any resistive losses in the associated transmission media. In an ac circuit, apparent power is equal to the observed/measured voltage (V) multiplied by the observed/measured current (I) in amperes (A) or $P = VI$. This power value includes both the power consumed by the load, the resistive losses in the associated transmission media, and the effects of any reactive components in the circuit. It is usually referenced in volt-amperes (VA). Reactive power represents the portion of the power used by the reactive elements (inductors and capacitors) and is measured in volt-amperes reactive.

Terminology, continued

True power is measured in watts and represents the power consumed solely by the connected load and any resistive losses in the associated transmission media. In dc circuits, it is equal to the observed/measured voltage multiplied by the observed/measured current in amperes or P = VI.

Manufacturers of electrical and electronic devices may show power values in VA in technical literature and nameplate data to signify apparent power consumed by a device, particularly if the equipment is powered by an ac source and contains reactive components that have an impact on the overall power consumed by the device. This is typical for items such as uninterruptible power supply equipment and ac/dc converter power supplies. However, many ICT equipment manufacturers indicate the power consumed by the device solely in watts.

In ac circuits, two additional concepts related to power are applicable. Peak power represents the maximum power available in an ac circuit at the specific moment in time when both the voltage and current are at their maximum values during the cyclic transitions present in an ac circuit (typically indicated as V_P and I_P). However, this does not represent the actual power consumed within the circuit and is not typically measured. A method was developed to measure power consumption in ac circuits based on determining the equivalent power consumption that would occur if dc power sources were used in lieu of ac power sources. For ac circuits, this is referred to as effective or root mean square (rms) power. Effective power is equal to the sustained power that is available during approximately 70 percent of the ac cycle within an ac circuit and is shown in watts; it represents the effective equivalent dc value of ac power:

$$P_A = 0.707 \times V_P \times I_P$$

The majority of measuring equipment used in ac circuits is configured to provide rms values.

The amount of current flow in a telecommunications circuit is usually small compared with that of a commercial electrical power line.

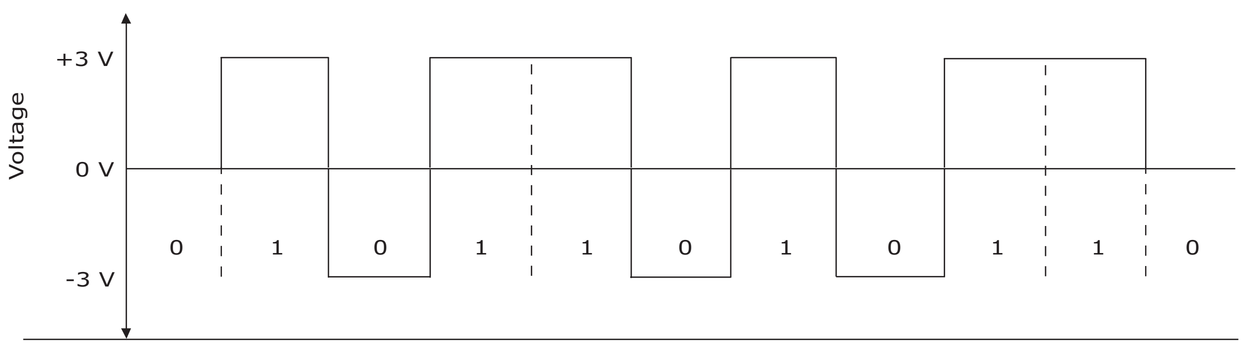
Terminology, continued

Signal

The information transmitted by an ICT system can originate in two fundamental forms—analog and digital. Analog data (e.g., speech waveform) is represented by the continuous variation of the message, whereas digital data is represented by a string of bits:

- Analog is derived from the term analogous, which means similar. Analog transmission uses continuously varying electrical signals that directly follow or are similar to the changes in loudness (amplitude) and frequency (tone) of the input signal (e.g., human voice). For instance, the transmitter of a telephone converts sound waves to an analog electrical signal that varies in amplitude (signal strength) directly with the loudness of the voice and varies in frequency directly with the tone of the voice.
- A digital signal is a discontinuous signal that changes from one state to another in a number of distinct steps within fixed time slots (see Figure 1.2). In its basic form, there are two states or signal levels—on and off. The on state translates to a one level corresponding to the digit one (1), and the off state translates to a zero level corresponding to the digit zero (0). Other means can be used to represent the two states (e.g., positive and negative voltage).

Figure 1.2
Digital signal



The digital message consists of a sequence of these digital pulses (bits) transmitted at regular and defined time intervals. These bits are usually rectangular in shape. Therefore, digitally transmitted information is a numerically encoded representation of input unlike analog transmissions, which reproduce an analog input in both frequency and amplitude.

Terminology, continued

Digital Transmissions

The basic unit of digital information is a bit (a contraction of the term binary digit). It is used to indicate the existence of two (binary) states or conditions (on or off). In legacy electronic systems, current flow was controlled to indicate an on or off state.

In modern electronic systems, it is less complicated to change a voltage level (on or off state) of an existing current flow than to establish a new current flow each time a pulse is needed. This on or off state is accomplished with an electrical voltage pulse within a predefined time slot, which is greater than a continuous base or reference level (voltage) present during an entire message transmission.

NOTE: This base voltage is often shown on graphs as a zero reference voltage for simplicity, but it actually can be a continuous current flow of a known and stable voltage level (e.g., 24 V).

EXAMPLE: When a device first starts a transmission, it will employ a nominal base voltage of some level (e.g., 24 V). A pulse of + 3 V would indicate an on state, and the line voltage would rise from 24 V to 27 V. When the voltage level returns to the 24 V base, it would represent an off state.

This example explains how a negative voltage pulse would work (unipolar nonreturn-to-zero). If a system were bipolar (+ 3 V and – 3 V), then – 3 V would indicate the change in base voltage from 24 V to 21 V and represent a negative pulse or an on state. In this case, an on state will be either + 3 V (27 V) or – 3 V (21 V), while an off state would be 24 V.

When a series of bits are grouped into a coded sequence (usually 8 bits), they make up basic building blocks that can convey information. The information that is conveyed depends on how a programmer references these building blocks to a table of information.

Modem

The transmission of digital data can be accomplished on a direct digital basis over a digital circuit, or it can be converted to an analog signal with a modulator/demodulator (modem). These modems convert the digital signal's 1s and 0s into two distinct analog frequencies, each representing a 1 or a 0. This analog signal then can be transmitted over a standard telephone circuit (e.g., analog plain old telephone service [POTS] line). The process is reversed at the opposite end to recreate the original digital signal.

Codec

The transmission of analog data (from video devices) can be converted from analog format to digital with a coder/decoder (codec). These codecs convert the amplitude changes of various frequencies into a digital format for transmission over digital transmission media. The process is reversed at the opposite end to recreate the video images.

Terminology, continued

Analog to Digital Conversion

For analog inputs (e.g., voice), the conversion to a digital signal for transmission over a digital media or medium involves a sampling process. An analog signal is sampled often enough that, when recreated, there is an acceptable facsimile of the original signal's data.

The most common process for voice conversion is called pulse code modulation (PCM). PCM samples the analog voice signal 8000 times per second to create a digital voice channel of 64,000 bits per second. Many access and service providers use this method. However, other methods to compress the voice into smaller data streams to reduce bandwidth and increase transmission efficiency are becoming popular for reasons such as the use of voice over Internet protocol and the increased use of wireless media in ICT systems (e.g., WiFi and cellular services).

Analog and Digital Technologies

The convergence of traditional telephony and distributed computing is now possible because both forms can transmit over one set of transmission protocols (e.g., Ethernet).

The local copper loop of the public switched telephone network (PSTN) was initially designed to carry POTS voice communication and signaling. The POTS signal range is transmitted between 300 and 3400 Hz, which is regarded as the minimum range for human speech to be clearly audible and recognizable.

Digital subscriber line (DSL) technology uses available bandwidth above the POTS range on existing PSTN copper loops by creating 4312.5 Hz wide channels between 10 and 100 kHz, depending on how the system is configured. Allocation of channels continues at higher and higher frequencies (up to 1.1 MHz for asymmetric digital subscriber line [ADSL]) until new channels are deemed unusable as a result of limitations in the PSTN copper loop (e.g., length).

ADSL is one form of DSL technology that allows faster data transmission over balanced twisted-pair cabling. Standard ADSL is full duplex, which uses 26,000 kHz to 137,825 kHz for upstream communication and 138 kHz to 1104 kHz for downstream communication.

Transmission characteristics of each frequency range (e.g., voice, data) need to be understood by the installer.

Megahertz (MHz) and Megabit (Mb)

It is important to understand the relationship between megahertz and megabit. Megahertz quantifies the bandwidth of a cabling system in a frequency range of interest (e.g., 1–600 MHz category 6/class E cabling). This relates to the information-handling capability of the media (e.g., size of the highway).

Megabit refers to the number of bits of information that can be transported over the media (e.g., vehicles on the highway). The number of bits that can be transported over the media is determined by the type of encoding scheme used in a system.

Terminology, continued

Bandwidth

Bandwidth represents the information-carrying capacity of a system. The overall bandwidth of an ICT system is related to the respective bandwidths of its component parts. The bandwidth or capacity of a system also may vary, depending on its length. Bandwidth typically is expressed in the range of analog frequencies (e.g., 0 Hz to 1 MHz) that can be transported or processed by the system.

Decibel (dB)

A measure of analog signal strength is a bel. This term is named in the honor of telephone pioneer Alexander Graham Bell. A bel is inappropriately large for ICT systems projects, so a decibel, or one tenth of a bel, is used. It is not an absolute value but a ratio of two signals, and it may be used for comparing power, current, or voltage.

System gain and attenuation are typically stated as decibel gain or decibel loss. For example, an amplifier may exhibit a power gain of 10 decibels (dB), or an optical fiber splice in a cabling system may exhibit a loss of 0.3 dB. Decibels express a ratio of two values, but the ratio is not linear.

The decibel is a logarithmic (as opposed to linear) function that allows large variations to be shown in small increments. Increases or decreases of 3 dB will result in a doubling or halving of the power. Increases or decreases of 6 dB will cause a doubling or halving of the voltage.

Increases or decreases of 10 dB for power and 20 dB for voltage or current will cause an increase or decrease of 10 times the original value. This moves the decimal point one place forward or backward in the numeric value. For example, if the input power is equal to 1 W, a decrease of 10 dB will have a value of 0.1 W; however, an increase of 10 dB will have an output of 10 W.

The formula for computing dB is:

$$\text{dB} = 10 \log (P_1 / P_2)$$

Where P_1 is the output power and P_2 is the input power.

A few examples of cabling system parameters that use decibel as a measurement of performance include:

- Crosstalk
- Insertion loss
- Return loss

Copper Cabling Media

Overview

With any copper cabling medium, a sufficient level of signal must be coupled through the medium from the transmitter to the receiver to drive the receiver.

The most effective and efficient transfer of a signal will occur at interfaces and connection points where all components share the same or similar characteristic impedance.

This section describes the electrical properties that make up characteristic impedance and how characteristic impedance can be impacted by hardware, design, and cabling installation methods or procedures.

American Wire Gauge (AWG)

The American wire gauge (AWG) system provides a standard reference for comparing various physical dimensions of conductor materials. Through usage and industrial standardization, the AWG sizing system is generally accepted worldwide for specifying and measuring wire and solid conductor diameters.

Historically, the sizes in the AWG system roughly represent the number of steps that were involved in the process of wire drawing. Therefore, the AWG numbers and the size of the wires they represent have an inverse relationship.

In the AWG system:

- Smaller numbers denote larger wires (because there are fewer drawing steps involved).
- Larger numbers denote smaller wires (because there are more drawing steps involved).

Additionally, the gauge number has the following relationships:

- A gauge change of three numbers approximately doubles or halves the conductor's cross-sectional area.
- A gauge change of three numbers approximately doubles or halves the conductor's resistance.
- A gauge change of six numbers approximately doubles or halves the conductor's diameter.

American Wire Gauge (AWG), continued

AWG values are for a single, solid, round conductor. The conductor diameters for the AWG system are based upon fixed diameters for the smallest size (36 AWG = 5 mil) and the largest size (4/0 AWG = 460 mil), where 1 mil is equal to ≈0.0254 millimeter (mm [0.001 inch (in)]). Table 1.1 provides values for AWG 27 to AWG 4/0.

The AWG of a stranded wire is determined by the cross-sectional area of the equivalent solid conductor. Because there are also small gaps between the strands, a stranded wire will always have a slightly larger overall diameter than a solid wire with the same AWG.

Table 1.1
Conductor size

AWG	1 Mil of an in	Conductor Size/mm Diameter	Conductor Size/in Diameter	CSA mm^2	Standard Conductor Sizes mm^2	dc Resistance (ohms per ≈ 305 m [1000 ft])	dc Resistance (ohms per ≈ 1 m [3.3 ft])
4/0	460.000	11.684	0.46	107.22	120	0.05	0.000164042
3/0	409.642	10.405	0.41	85.03	95	0.06	0.00019685
2/0	364.797	9.266	0.365	67.43	70	0.08	0.000262467
1/0	324.861	8.251	0.325	53.48	70	0.10	0.000328084
1	289.297	7.348	0.289	42.41	50	0.13	0.000426509
2	257.626	6.544	0.258	33.63	35	0.16	0.000524934
3	229.423	5.827	0.229	26.67	35	0.20	0.000656168
4	204.307	5.189	0.2045	21.15	25	0.25	0.00082021
5	181.941	4.621	0.182	16.77	25	0.30	0.000984252
6	162.023	4.115	0.162	13.30	16	0.4	0.001312336
7	144.285	3.665	0.144	10.55	16	0.5	0.00164042
8	128.490	3.264	0.128	8.37	10	0.6	0.001968504
9	114.424	2.906	0.114	6.63	10	0.8	0.002624672
10	101.897	2.588	0.102	5.26	6	1.0	0.00328084
11	90.742	2.305	0.091	4.17	6	1.3	0.004265092
12	80.808	2.053	0.081	3.31	4	1.6	0.005249344
13	71.962	1.828	0.072	2.62	4	2.0	0.00656168
14	64.084	1.628	0.064	2.08	2.5	2.5	0.0082021
15	57.068	1.450	0.057	1.65	2.5	3.2	0.010498688
16	50.821	1.291	0.051	1.31	1.5	4.0	0.01312336
17	45.257	1.150	0.045	1.04	1.5	5.0	0.016404199
18	40.303	1.024	0.0403	0.82	1	6.4	0.020997375
19	35.891	0.912	0.0359	0.65	1	8.1	0.026574803

American Wire Gauge (AWG), continued

Table 1.1, continued
Conductor size

AWG	1 Mil of an in	Conductor Size/mm Diameter	Conductor Size/in Diameter	CSA mm^2	Standard Conductor Sizes mm^2	dc Resistance (ohms per ≈ 305 m [1000 ft])	dc Resistance (ohms per ≈ 1 m [3.3 ft])
20	31.961	0.812	0.032	0.52	1	10.1	0.033136483
21	28.462	0.723	0.0285	0.41	0.5	12.8	0.041994751
22	25.347	0.644	0.0253	0.33	See Note	16.2	0.053149606
23	22.572	0.573	0.0226	0.26	See Note	20.3	0.06660105
24	20.101	0.511	0.0201	0.20	See Note	25.7	0.084317585
25	17.900	0.455	0.0179	0.16	See Note	32.4	0.106299213
26	15.941	0.405	0.0159	0.13	See Note	41.0	0.134514436
27	14.196	0.361	0.0142	0.10	See Note	51.4	0.168635171

NOTE: Power cables generally do not have sizes below 0.5 mm^2. Control cables generally do have sizes below 0.5 mm^2.

AWG = American wire gauge
CSA = Cross-sectional area
dc = Direct current
ft = Foot
in = Inch
m = Meter
mil = Millionth
mm = Millimeter
mm^2 = Square millimeter

Physical Properties

Resistance

For metallic cables, the electrical energy of the signals is typically transmitted over copper conductors. Copper is preferred because it offers low resistance to the flow of electrical energy.

Resistance is the property of a conductor to resist the flow of electricity through it. Resistance is expressed in ohms. One ohm of resistance will allow 1A of current to flow when 1V of electrical pressure is applied. This is stated mathematically in Ohm's law (see Figure 1.3) as:

$$V = I \times R$$

or

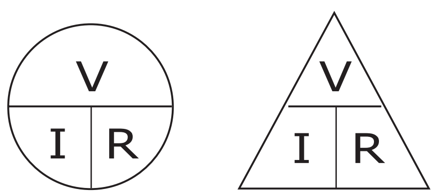
$$R = V / I$$

or

$$I = V / R$$

Where V is voltage in volts; I is current in amperes; and R is resistance in ohms.

Figure 1.3
Ohm's law



V = Voltage in volts
I = Current in amperes
R = Resistance in ohms

Ohm's law values are easily solved. Placing a finger over the I (in Figure 1.3) shows that V is divided by R. Placing a finger over the R shows that V is divided by I. Placing a finger over the V shows that I is multiplied by R.

Higher temperatures increase the conductor resistance by approximately 2 percent for each ≈5.5 degrees Celsius (ºC [10 degrees Fahrenheit (ºF)]) rise.

Resistance changes in proportion to length (e.g., doubling the length of the cable doubles its resistance).

The diameter of the conductors of a pair is maintained at a close tolerance to keep any resistance unbalance to a minimum. Such unbalance contributes to undesirable distortion of the signal.

Physical Properties, continued

Inductance

Inductance is a property of an electromagnetic field built around a conductor that opposes any changes in current flow in a circuit, both ac and varying dc. When dc flows through a conductor, the field is steady. An ac signal causes the lines of force to constantly build and collapse. The opposition to varying current results in energy loss, particularly for high-frequency signals. The basic unit of inductance is a henry (H).

Inductive coupling is the transfer of energy from one circuit to another through this field (e.g., power lines on a utility pole can inductively couple ac voltage and current onto communications cables).

Inductive reactance is a force that opposes a change in the direction of current flow on a conductive path. Inductive reactance (X_L) is measured in ohms. The formula for inductive reactance is:

$$X_L = 2\pi fL$$

Where:

π = 3.1416

f = frequency (Hz)

L = inductance (H)

Inductive reactance is directly proportional to the frequency (e.g., as frequency increases, inductive reactance increases).

Capacitance

Capacitance is a property of conductors that allows storage of electric charges when potential differences (voltages) exist between the conductors. Capacitance causes a voltage difference between two wires when separated by insulation. The insulation or dielectric (non-conductive material) separates the two wires, resulting in a buildup (or storage of electric charges) of capacitance between the wires.

Capacitance is measured in farads (F). Normally, capacitors are measured in microfarads (one millionth of a farad), nanofarads (one billionth of a farad), or picofarads (one trillionth of a farad).

Cable normally exhibits some level of capacitance. Capacitance in cable must be minimized. Capacitance may be affected by improper cable installation. Because it is an important element of the cable's characteristic impedance, changes in capacitance and inductance may degrade the quality of transmission through the cable.

Physical Properties, continued

In multi-conductor cables, two capacitance factors are observed:

- Mutual capacitance—the capacitance between two conductors.
- Unbalanced capacitance—the capacitance between a conductor and ground.

Capacitive reactance is a force that opposes a change in the applied voltage waveform across a conductive path. Capacitive reactance (X_C) is measured in ohms. The formula for capacitive reactance is:

$$X_C = 1/2\pi fC$$

Where:

π = 3.1416

f = frequency (Hz)

C = capacitance (F)

Capacitive reactance is inversely proportional to the applied frequency (e.g., as frequency increases, capacitive reactance decreases).

Impedance (Z)

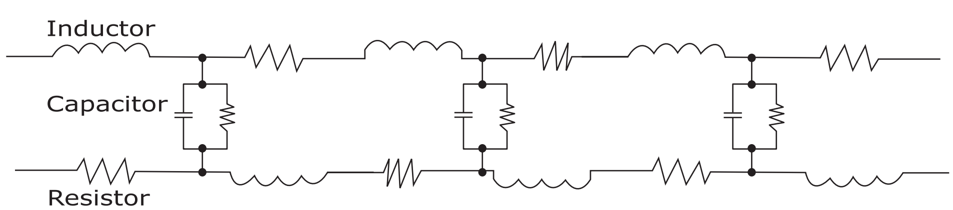
In ac circuits, the total opposition to current flow is called impedance, which is measured in ohms. This is the combined effects of resistance, inductive reactance, and capacitive reactance of the circuit:

$$Z = R^2 + (X_L - X_C)^2$$

Characteristic Impedance

Characteristic impedance is defined as the input impedance of a uniform analog transmission line of infinite length. An example of a transmission line is a balanced twisted-pair of wires. To a signal, a transmission line appears as a continuous configuration of resistors, capacitors, and inductors (see Figure 1.4).

Figure 1.4
Schematic of a transmission line



Physical Properties, continued

Every cable or transmission line has a characteristic impedance. The value of the characteristic impedance is determined by the:

- Metallic material and the diameter of the conductors.
- Distance between the conductors.
- Insulating value (dielectric constant) of the materials separating them.

Cables are designed to achieve constant characteristic impedance independent of the cable length. For example, if ≈30 meter (m [100 foot (ft)]) length of cable has a characteristic impedance of 100 ohms, it will still be 100 ohms if the length is doubled or tripled for a given frequency.

All components of a system must reference the same value of input and output impedance for maximum signal (energy) transfer to occur at the interface point. Impedance matching becomes even more critical at higher frequencies. Impedance mismatches can cause:

- Attenuation, distortion, or corruption of transmitted and received signals.
- Damage to equipment and components.

Most balanced twisted-pair cabling used for ICT exhibits a characteristic impedance of approximately 100 ohms ± 15 percent at 1 MHz at a temperature of ≈20 ºC (68 °F).

Insertion Loss (Attenuation)

Insertion loss (attenuation) is:

- The measure of signal loss resulting from the insertion of a component, link, or channel between a transmitter and receiver.
- The measure of how much a signal is reduced in amplitude (relative power) as it is transmitted over cable.
- Measured in decibels per unit length at a given frequency. As frequency or length increases, attenuation increases.
- A loss of usable signal to the load or receiver. The lower the decibel value, the better. Higher attenuation means less available signal.

There are times when attenuation is intentionally added, usually with an attenuator, so that the signal is reduced at the receiver end. This may be necessary to avoid signal distortion and corruption and to prevent damage to receiving equipment and components because of excessive power levels on the received signal. This practice may also be referred to as "padding down the circuit."

Cabling Media Properties

Return Loss

When the termination (load) impedance does not match or equal the value of the characteristic impedance of the transmission line (e.g., 100 ohm impedance), some of the signal energy is reflected back toward the transmitter and is not delivered to the receiver. The amount of reflected energy is affected by the degree of impedance mismatch between the receiver and the transmitter.

Impedance variations can result from cable or connector tolerances and from installation variables (e.g., cable bends, stresses imposed on cables, mixed manufacturers components) as well as variations within and between cables and connectors. The resulting effects on the signal energy can be measured and expressed as return loss.

Return loss is a ratio of the power of the outgoing signal to the power of the reflected signal and is expressed in decibels. Return loss values are typically a negative decibel value, with a greater negative value indicating a better return loss (e.g., a return loss of -50 dB is better than a return loss of -5 dB).

In systems where a single pair is used for bidirectional signaling (alternating transmission from both ends of the pair), any reflected signal is seen by the transceiver that originally sent the signal as noise combining with any signal generated by the transceiver at the distant end. This is especially important in applications that use bidirectional transmission.

Return loss is the primary indicator of poor installation practices. Some examples of damage that may be caused during installation and how it might affect the characteristic impedance of the cable include the following:

- Exceeding the cable pulling tension can lead to stretching of the conductors, which would cause an increase in resistance within the conductor; a smaller gauge conductor equals higher resistance.
- Untwisting of the pairs can affect inductance between the conductors of a twisted-pair.
- Removing too much cable sheath or damage to the conductor’s insulation can affect the capacitance of the conductor.
- Improperly made, damaged, or contaminated cable connections.

Nominal Velocity of Propagation (NVP)

The nominal velocity of propagation (NVP) is a ratio of the speed of transmission along a cable relative to the speed of light in a vacuum. It is often stated in percentages. Test equipment uses NVP to determine the length of a cable.

Connectors

Connecting hardware is a mechanical device (e.g., plug, jack) attached to the end of a cable or to a piece of equipment. Connecting hardware is often referred to as a connector. When two connectors are mated, electrical signals (in copper systems) or light impulses (in fiber systems) can be transferred from one cable or piece of equipment through the connectors to the other cable or piece of equipment.

Connectors are as essential to the integrity of an ICT network as the cable itself. Together, the cable, the connectors, and the active equipment devices form the telecommunications channel through which information moves.

The connector provides a means for the physical attachment from the media to:

- An active ICT device (e.g., transmitter, receiver, transceiver).
- A passive ICT device (e.g., patch panel to patch panel).

Along a cable path, connections can contribute to the loss of signal (insertion loss) from transmitter to receiver. The role of the connector is to provide a coupling mechanism that minimizes loss of signal in the circuit.

Some of the key factors in establishing a good connection and minimizing loss of signal include:

- Fit—The connectors must be sufficiently secure when mated together to prevent separating unintentionally.
- Alignment—The connectors must provide the physical alignment necessary to properly complete the link.
- Functionality—The connection must provide for the efficient transfer of signal from cable to connector.
- Configuration—Connectors must be designed specifically for the media and the devices being connected.

Durability is demonstrated by the connectors' ability to withstand hundreds of insertion and withdrawal cycles without failing. This is expressed as mean time between failure.

Most connectors are classified as male and female. In general, outlets or jacks are female connectors, and plugs are male connectors.

Balanced Twisted-Pair Cable

Overview

Balanced twisted-pair cables are commonly used for ICT system installations. The transmission characteristics of telecommunications cables, cords, and connectors depend on the frequency of the applied signal. These differences are most apparent at frequencies above 1 MHz.

Balanced twisted-pair cables have a nominal characteristic impedance of 100 ohms at 100 MHz. The improvement in attenuation for high-performance cables is realized through improved design and materials. Likewise, an improvement of upward of 10 dB in crosstalk performance is attained through better balance and pair-twist optimization. These balanced twisted-pair cables provide increased signal-to-noise margins, which equate to higher data throughput (fewer bit errors), a longer reach, or higher transmission rate capability.

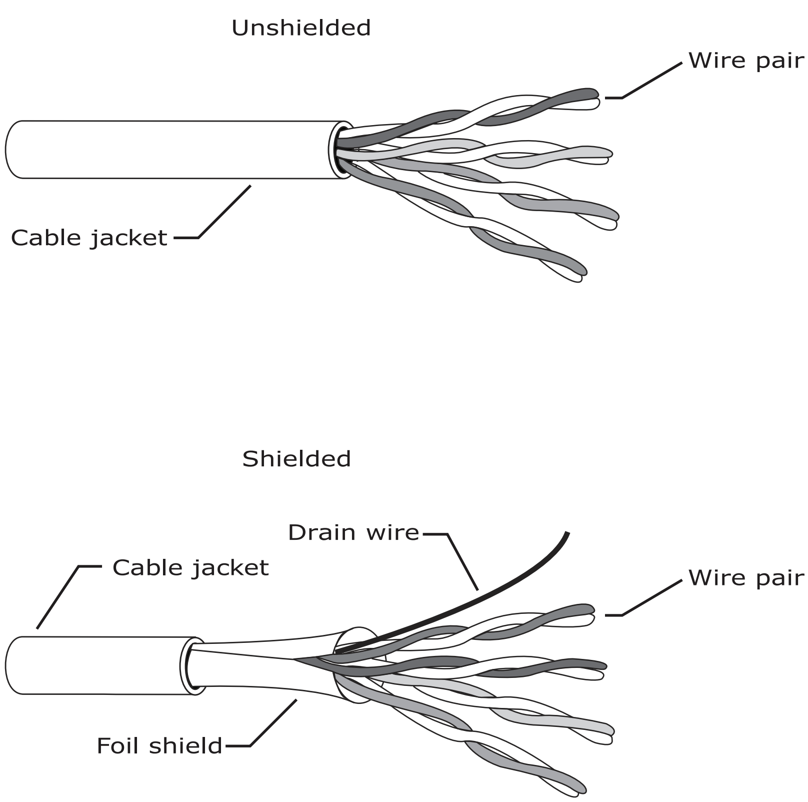
The transmission parameters of greatest importance include the:

- Signal attenuation as a function of frequency.
- Signal reflections at terminations.
- Amount of noise relative to the received signal.

Cable Construction

Typical balanced twisted-pair cables are shown in Figure 1.5.

Figure 1.5
Typical balanced twisted-pair cable



Cable Construction, continued

Insulation

Copper wires must be physically separated. In the case of a single pair of wires, contact of the two wires (short circuit) will prevent the signal from traveling down the transmission line. The selection of material to cover the wire involves economics as well as tradeoffs in characteristics desired for the application and installation environment.

An electrically efficient insulation is nearly always desired, but a tradeoff may be required (e.g., to obtain insulation capable of meeting plenum cable requirements). Similarly, less effective insulation may be used to secure more physically robust characteristics.

The insulation materials selected can affect the physical size of the cable assembly and determine two of the four primary electrical cable characteristics:

- Mutual capacitance of a pair.
- Conductance.

The mutual capacitance value depends on the type of conductor insulating material and the material's diameter (thickness).

NOTE: One primary performance indicator (in terms of bandwidth) of a cable is the mutual capacitance value of paired conductors. Typically, the lower the value, the higher the bandwidth.

The conductance of a cable indicates the potential for current to leak through the insulation. Conductance is inversely related to resistance.

Pair Twist

To maintain consistent transmission quality in an ICT cabling system, the two wires of an insulated balanced twisted-pair cable are uniformly twisted together. The length of this twist (or pair lay or pitch) usually varies from ≈6 mm (0.24 in) to ≈150 mm (6 in). The ICT systems cabling is manufactured so that no two pairs in a cable will have the same pair lay length within the same 25-pair binder. Because of the different twist rates in a multipair cable, the physical length of untwisted pairs is not equal. The effects of both capacitance unbalance and electromagnetic induction are improved by twisting the pairs.

Proper cable design and twisting of the pairs minimizes detrimental crosstalk and noise. It is necessary that the installer recognize the importance of each individual pair twist and maintain the same pair twist for each individual pair when terminating the conductors to the connecting hardware. Pair twist may vary from pair to pair within a given cable.

Cable Construction, continued

Screened/Shielded Twisted-Pair Cable

Screened/shielded twisted-pair cable is becoming more widely used as the requirements for high-performance applications demand greater protection for signals from outside noise sources. Although screened/shielded cabling may be more expensive than unshielded twisted-pair (UTP) cabling, screened/shielded cabling offers a higher immunity to EMI and may be used in areas susceptible to EMI, possibly eliminating the need for metallic conduit in some environments.

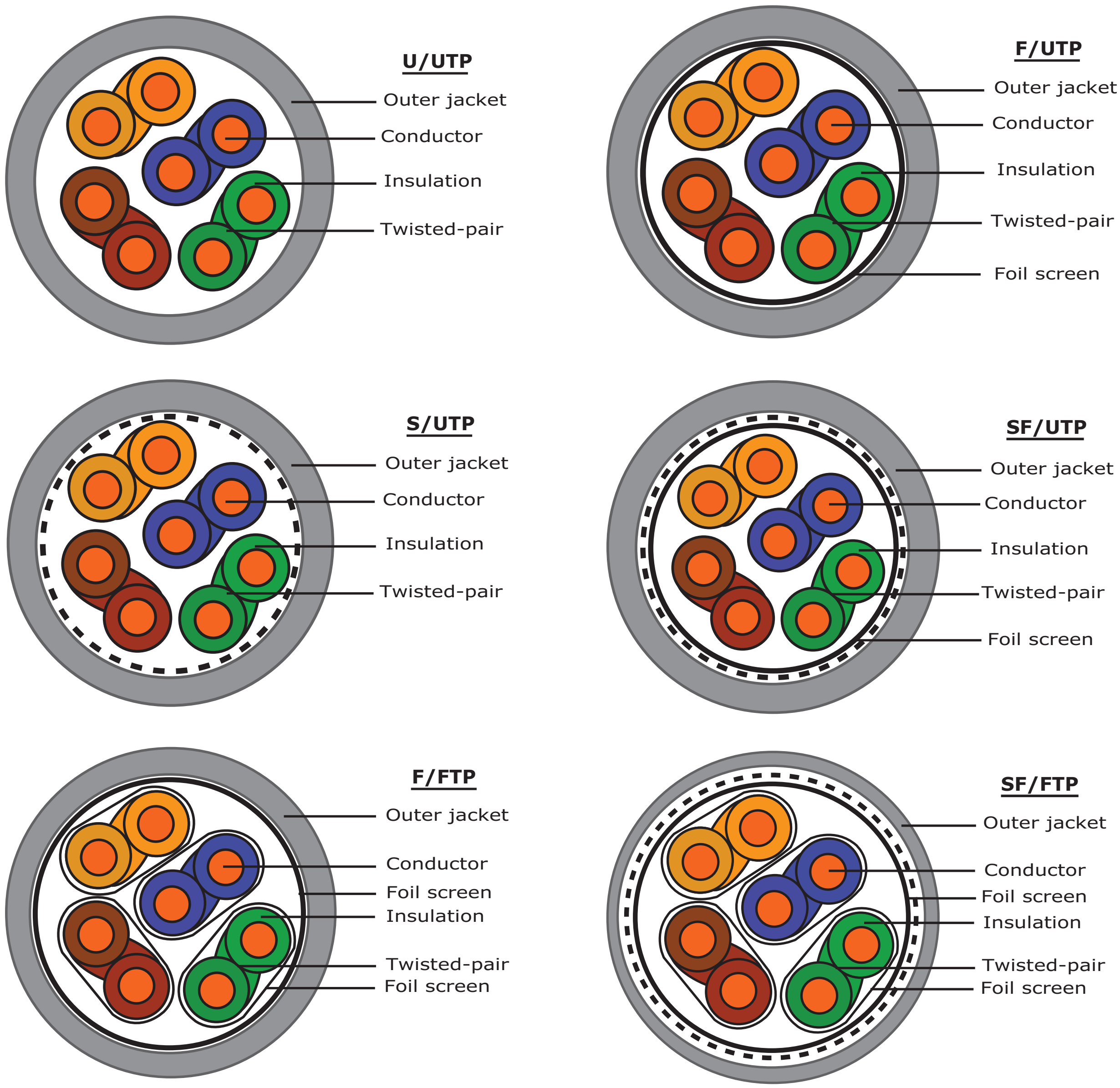
The construction of screened/shielded cables differs significantly from one manufacturer to another. These cable types feature a number of different configurations of braid/mesh screen, foil shield, or a combination of braid screen and foil shield.

Cable designations define cable construction of the overall cable followed by the cable construction of the individual cable pairs (e.g., F/FTP).

Cable Construction, continued

See Figure 1.6 for examples of screened/shielded and unshielded balanced twisted-pair cable designs.

Figure 1.6
Examples of screened/shielded and unshielded balanced twisted-pair cable designs



- - - - = Braid screen
F/FTP = Foil-screened foil-screened twisted-pair
F/UTP = Foil-screened unscreened twisted-pair
S/UTP = Braid-screened unscreened twisted-pair
SF/FTP = Braid-screened-foil-screened foil-screened twisted-pair
SF/UTP = Braid-screened-foil-screened unscreened twisted-pair
U/UTP = Overall unshielded twisted-pair with unshielded twisted-pair

Cable Construction, continued

When foil is used, an optional drain wire may be used inside the cable adjacent to the conductive side of the foil screen. Cable manufacturers do not always employ this practice when placing a foil over each individual pair within the cable.

A screened/shielded twisted-pair cable must be terminated in a shielded modular connector in order to optimize the product's transmission performance characteristics. The shielded connector is enclosed by a metallic, EMI-resistant housing. The dressing block for cable pairs typically fits within the walls of the connector body so that, when terminated, the twisted-pairs and insulation displacement contact (IDC) connectors are completely enclosed by the metal, which forms an EMI shield.

Cabling system manufacturers provide details of their installation and termination practices to maintain the integrity of the cabling system performance. Proper installation and termination practices will vary based on the cable type and connector combination.

Cabling Performance Classification

Category/class rated cable may be used to support many types of services, including voice and data cabling, electronic safety and security systems, building automation systems, audiovisual systems, and other types of ICT systems.

All category/class rated cables have the following characteristics:

- Composed of insulated conductors twisted together to form circuit pairs.
- Provide support for noise cancellation techniques through conductor twisting.
- Generally have a characteristic impedance of 100 ohm (± 15 ohm).
- Conductor sizes are 22 AWG [0.64 mm (0.025 in)] to 24 AWG [0.51 mm (0.020 in)].

Balanced twisted-pair cabling performance is described using a scale based on classes or categories defined by the International Organization for Standardization (ISO)/International Electrotechnical Commission, and Telecommunications Industry Association (TIA). Whereas TIA uses the term category to describe performance of both components and the system, ISO defines component performance by the term category; cabling link or cabling channel system performance is defined by the term class, short for classification.

Cable Construction, continued

Specifications for several performance levels of balanced twisted-pair cable and associated connecting hardware are shown in Table 1.2.

Table 1.2
Balanced twisted-pair cabling channel performance

TIA Categories	ISO Categories/Classes	Frequency
Category 3	Category 3/class C	16 MHz
Category 5e	Category 5e/class D	100 MHz
Category 6	Category 6/class E	250 MHz
Category 6_A	Category 6_A/class E_A	500 MHz
N/A	Category 7/class F	600 MHz
N/A	Category 7_A/class F_A	1000 MHz
Category 8	Category 8.1/class I*	2000 MHz
N/A	Category 8.2/class II†	2000 MHz

* Backwards compatible with category 6_A/class E_A using 8P8C connectors.
† Interoperable with category 7_A/class F_A.

8P8C = 8-position, 8-contact
ISO = International Organization for Standardization
MHz = Megahertz
N/A = Not applicable
TIA = Telecommunications Industry Association

To improve information throughput, significant performance changes have been made to balanced twisted-pair cables. The installer must consider the relevant aspects of cable performance defined in the standards for the appropriate cabling category/class during installation and testing.

Cable Construction, continued

Conductor Color Codes

Individual conductors are referred to as tip and ring conductors. Each pair has a tip and a ring conductor or a positive and negative conductor, respectively. Installers must be able to identify individual pairs within the cable and the individual conductors within each pair. Color codes have been developed to enable the installer to quickly perform this identification.

The colors used to identify tip conductors are different from the colors used to identify ring conductors. There are five colors associated with tip conductors (white, red, black, yellow, and violet) and five different colors associated with ring conductors (blue, orange, green, brown, and slate). When two conductors are paired, two different colors identify the pair number. There are 25 possible color combinations when the five tip and five ring color codes are mixed. However, two tips or two rings are never used to make a pair.

Tables 1.3 and 1.4 provide conductor color codes for 4-pair and 25-pair cables.

Table 1.3
Color codes for 100-ohm balanced twisted-pair patch cables

Pair	Identification	Color Conductor Color Code
Pair 1	Tip Ring	White-blue (W-BL) Blue-white (BL-W)
Pair 2	Tip Ring	White-orange (W-O) Orange-white (O-W)
Pair 3	Tip Ring	White-green (W-G) Green-white (G-W)
Pair 4	Tip Ring	White-brown (W-BR) Brown-white (BR-W)

Table 1.4
High pair-count cable, color-coded pairs

	Ring Conductors				
Tip Conductors	Blue 1st Pair	Orange 2nd Pair	Green 3rd Pair	Brown 4th Pair	Slate 5th Pair
White (1–5)	1	2	3	4	5
Red (6–10)	6	7	8	9	10
Black (11–15)	11	12	13	14	15
Yellow (16–20)	16	17	18	19	20
Violet (21–25)	21	22	23	24	25

NOTE: The tip color does not identify a specific pair number until the combination of the tip and ring colors are matched.

Cable Construction, continued

To identify the pair number, the tip and ring colors must be viewed together (e.g., the white/blue pair is actually a white tip and a blue ring). White indicates the pair is between pairs 1 and 5, while blue indicates it is the first pair of the group.

Other examples include:

- Black/brown pair—Black indicates pairs between 11 to 15 while brown indicates it is the fourth pair, leading to black/brown being the 14th pair.
- Yellow/orange pair—Yellow indicates pairs 16-20 while orange indicates the second pair, making yellow/orange the 17th pair.

The standard color code can be used to identify up to 25 pairs without duplicating any pair color combinations.

For cables with more than 25 pairs, the first group of 25 pairs is formed into a bundle and has a colored binder (tape or thread) placed around the bundle. Additional bundles (25 pairs) have their own unique colored binder. The colored binder wraps follow the same color code as the individual pair color code. They are referred to as binder groups or binders.

The white/blue binder group is the first and contains cable pairs 1 to 25; the white/orange binder group is the second and contains cable pairs 26 to 50; the red/blue binder group is the sixth and contains cable pairs 126 to 150.

This system of 25-pair binder groups defines up to 625 pairs of cable (25 binders times 25 pairs per binder = 625 total pairs). However, the final 25 pairs in the violet/slate binder group are not used, leaving a total of 600 pairs. On some smaller cables (100 pairs or less), the manufacturer may mark the binders by the ring color only since it can be assumed that the tip color is white. See Table 1.5 for a list of pair and binder groups.

Cable Construction, continued

Table 1.5
High pair-count cable, color-coded pairs, and binder groups

Number	Pair Tip	Ring	Binder Group Color	Pair Count
1	White	Blue	White-Blue	001–025
2	White	Orange	White-Orange	026–050
3	White	Green	White-Green	051–075
4	White	Brown	White-Brown	076–100
5	White	Slate	White-Slate	101–125
6	Red	Blue	Red-Blue	126–150
7	Red	Orange	Red-Orange	151–175
8	Red	Green	Red-Green	176–200
9	Red	Brown	Red-Brown	201–225
10	Red	Slate	Red-Slate	226–250
11	Black	Blue	Black-Blue	251–275
12	Black	Orange	Black-Orange	276–300
13	Black	Green	Black-Green	301–325
14	Black	Brown	Black-Brown	326–350
15	Black	Slate	Black-Slate	351–375
16	Yellow	Blue	Yellow-Blue	376–400
17	Yellow	Orange	Yellow-Orange	401–425
18	Yellow	Green	Yellow-Green	426–450
19	Yellow	Brown	Yellow-Brown	451–475
20	Yellow	Slate	Yellow-Slate	476–500
21	Violet	Blue	Violet-Blue	501–525
22	Violet	Orange	Violet-Orange	526–550
23	Violet	Green	Violet-Green	551–575
24	Violet	Brown	Violet-Brown	576–600
25	Violet	Slate	25th binder is not used.	

Cable Construction, continued

When cable exceeds 600 pairs each, 600 pairs (24 binders) are wrapped in a colored super-group binder, which denotes 600 pairs. The color code changes from the normal tip/ring identifiers to a simple tip color (e.g., white indicates 1 to 600 pairs; red indicates 601 to 1200 pairs; black indicates 1201 to 1800 pairs).

Balanced Twisted-Pair Cable Jacket Listing Designations

Listings for telecommunications cables and pathways for interior building installations are based on their characteristics when exposed to fire (see Table 1.6). Many codes, standards, and regulations related to this subject are used throughout the world. The cable marking types presented in Table 1.6 for balanced twisted-pair cable are used when determining which cable type is appropriate for the space being cabled. The table does not represent a cable substitution hierarchy nor show all possible cable markings. Refer to applicable codes, standards, and regulations for such cable substitution hierarchy.

Table 1.6
Copper cable listing designations

Cable Marking	Type
CMP (FT6)	Communications plenum
CMR (FT4)	Communications riser
CMG (FT4)	Communications general
CM (FT1)	Communications
CMX (FT1)	Communications limited
CMUC	Undercarpet communications
LSZH (LSF)	Low smoke zero halogen (low smoke and fume)

Balanced Twisted-Pair Cabling Properties

In addition to the cabling characteristics inherent to all copper cabling, balanced twisted-pair cabling has additional characteristics related to its construction.

Crosstalk

The unwanted transfer of a signal's electromagnetic energy from one or more circuits to other circuits is called crosstalk. This transfer may be between pairs in close proximity or between adjacent cables.

The level of crosstalk increases when frequency or cable length increases although this increase is not directly proportional.

Three basic types of crosstalk are of interest for balanced twisted-pair cabling:

- Near-end crosstalk (NEXT)
- Attenuation-to-crosstalk ratio, far-end (ACRF)
- Alien crosstalk (AXT)

Crosstalk is decreased by pair twists, cable lay, shielding, and physical pair separation, all of which are achieved during the cable manufacturing process.

Crosstalk values are typically a negative decibel value, with a greater negative value indicating a lower crosstalk being present (e.g., a crosstalk value of -50 db is better than a crosstalk value of -5 db).

Near-End Crosstalk (NEXT)

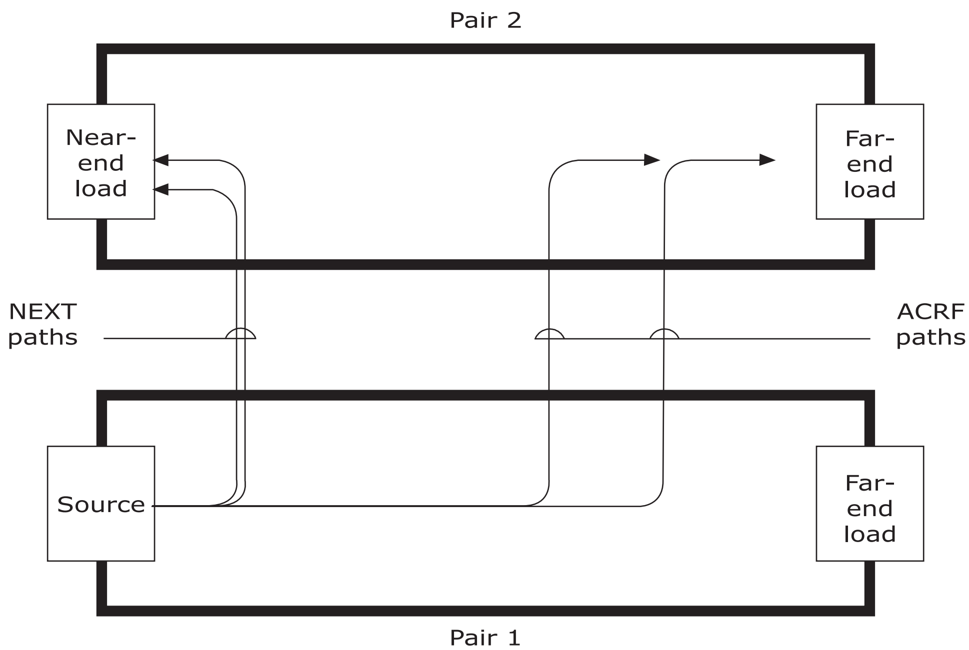
NEXT is a measure of the unwanted signal coupling from a transmitter at the near end into another pair measured at the near end. When NEXT measurements are made with field test equipment, there are six combinations of pair-to-pair NEXT associated with a 4-pair cabling link or channel:

- Pair 1–pair 2
- Pair 1–pair 3
- Pair 1–pair 4
- Pair 2–pair 3
- Pair 2–pair 4
- Pair 3–pair 4

Balanced Twisted-Pair Cabling Properties, continued

Figure 1.7 illustrates both NEXT and ACRF paths for two pairs. NEXT and ACRF are expressed in decibels.

Figure 1.7
Crosstalk paths



ACRF = Attenuation-to-crosstalk ratio, far-end
NEXT = Near-end crosstalk

The lower the quantity of signal transferred between circuits, the smaller the received-to-transmitted signal ratio and the larger the decibel crosstalk loss value.

Attenuation-to-Crosstalk Ratio, Far-end (ACRF)

ACRF is the measure of the unwanted signal transfer (coupling) that is assessed by applying a signal on one pair at the near end and measuring the signal transfer level on any disturbed pair at the receiving end of the cable. ACRF is measured and expressed in decibels at the opposite end from which the source signal is transmitted.

The value for ACRF varies, depending upon the length of the cable. In order to obtain consistent values for ACRF, regardless of cable length, insertion loss must be factored into the measurement. The insertion loss of the disturber pair is subtracted from the far-end crosstalk measurement and reported as ACRF.

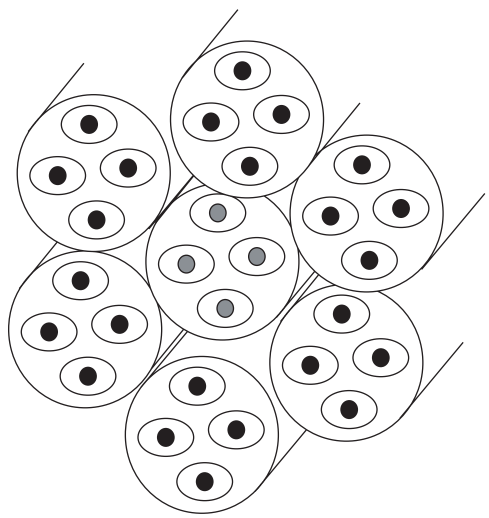
Balanced Twisted-Pair Cabling Properties, continued

Alien Crosstalk (AXT)

AXT is the unwanted signal coupling from a disturbing pair of a 4-pair cable channel, permanent link, or component to a disturbed pair of another 4-pair channel, permanent link, or component.

There are several variants of AXT, including field test measurement orientation considerations and recommended test strategies for field testing as described in applicable standards and related amendments. Figure 1.8 depicts the six-around-one laboratory test methodology that is used to qualify cables for AXT compliance. These AXT measurements are made while the cables are placed in this configuration.

Figure 1.8
Six-around-one alien crosstalk (AXT) measurements configuration



The cabling system manufacturer's laboratory tests are made to simulate typical field installation scenarios such as bundling and dressing cables in telecommunications pathways and spaces. To properly mitigate AXT, installers should consult with the balanced twisted-pair cabling manufacturers to qualify maximum allowable cable bundling distances for their products.

When field testing for AXT, installers must select cables to be tested within the same bundle.

Balanced Twisted-Pair Cabling Properties, continued

Installation Considerations Related to Alien Crosstalk (AXT) and Bundling of Cabling

Screened/shielded varieties may be installed without installation restrictions related to bundling of different manufacturers' cables within the same pathway. There are no concerns related to screened/shielded cabling that the AXT requirements specified in applicable standards will be exceeded.

Unshielded varieties of category 6_A/class E_A and higher balanced twisted-pair cabling (e.g., UTP) should not be installed in cable bundles composed of different manufacturers' cables within the same pathway. Table 1.7 presents additional guidance related to the installation of all forms of category 6_A/class E_A and higher balanced twisted-pair cabling.

Table 1.7
Cable bundling restrictions when cables are produced by different manufacturers

Cable Bundling Conditions Within a Pathway (e.g., conduit, basket tray)	Category 6_A/Class E_A and Higher Balanced Twisted-Pair Screened/Shielded Cabling (e.g., F/UTP, S/FTP)	Category 6_A/Class E_A and Higher Balanced Twisted-Pair Unshielded Cabling (e.g., UTP)
Cables produced by different manufacturers that are bundled within the same pathway	Allowed	Not allowed
Cables produced by different manufacturers and bound in adjacent bundles within the same pathway	Allowed	Allowed
Cables produced by different manufacturers that are unbundled within the same pathway	Allowed	Allowed

F/UTP = Overall foil-screened with unshielded twisted-pair
S/FTP = Overall braid-screened with foil-screened twisted-pair
UTP = Unshielded twisted-pair

For any of the allowed cable bundling configurations described in Table 1.7, there are no concerns that the AXT requirements specified in applicable standards will be exceeded.

Balanced Twisted-Pair Cabling Properties, continued

Mixing Higher Cabling with Lower Performing Cabling

Screened/shielded varieties (e.g., F/UTP, S/FTP) of category 6_A/class E_A and higher balanced twisted-pair cabling may be installed without installation restrictions related to mixing with lower category cables that are either bundled together or unbundled within the same pathway or grouped in adjacent bundles within the same pathway. There are no concerns related to shielded cabling that the AXT requirements specified in applicable standards will be exceeded.

Unshielded varieties of category 6_A/class E_A and higher balanced twisted-pair cabling (e.g., UTP) should not be installed in cable bundles composed of category 6_A/class E_A and higher balanced twisted-pair cabling mixed with lower performing cabling within the same bundle within a pathway. Table 1.8 presents additional guidance related to the installation of all forms of category 6_A/class E_A and higher balanced twisted-pair cabling.

Table 1.8
Mixing category 6_A/class E_A and higher cabling with lower performing cabling

Cable Bundling Conditions Within a Pathway (e.g., conduit, basket tray)	Category 6_A/Class E_A and Higher Balanced Twisted-Pair Screened/Shielded Cabling (e.g., F/UTP, S/FTP)	Category 6_A/Class E_A and Higher Balanced Twisted-Pair Unshielded Cabling (e.g., UTP)
Category 6_A/class E_A and higher cabling mixed with lower performing cabling that are bound within a bundle within the same pathway	Allowed	Not allowed
Category 6_A/class E_A and higher cabling mixed with lower performing cabling that are bound in adjacent bundles within the same pathway	Allowed	Allowed
Category 6_A/class E_A and higher cabling mixed with lower performing cabling that are not bundled within the same pathway	Allowed	Allowed

F/UTP = Overall foil-screened with unshielded twisted-pair
S/FTP = Overall braid-screened with foil-screened twisted-pair
UTP = Unshielded twisted-pair

Balanced Twisted-Pair Cabling Properties, continued

Propagation Delay

Propagation delay is the time interval required for a signal to be transmitted from one end of a circuit to the other. For 100 ohm 4-pair cables, the maximum allowable propagation delay is measured at 10 MHz for all categories of cabling. The delay is expressed in nanoseconds and is length dependent.

Delay Skew

Delay skew is the difference in the propagation delay between the slowest and fastest pairs within the same cable sheath. For 100 ohm 4-pair cables, the maximum allowable propagation delay skew is measured at 10 MHz for all categories of cabling. This measurement is expressed in nanoseconds and is length dependent.

Modular Twisted-Pair Connectors

Best practices and industry standards require that balanced twisted-pair cable be terminated using insulation displacement contact (IDC) type connections. An IDC connection permits the termination of an insulated conductor without stripping insulation from the conductor. As the insulated conductor is inserted between two or more sharp edges of the contact, the insulation is displaced, allowing contact to be made between the conductor and the connector terminal and providing a gas-tight termination.

Connectors typically have two different types of contacts. Most connectors use IDCs designed for solid conductors, while modular plugs also may use insulation piercing contacts (IPCs) designed for stranded conductors only. Some modular plugs with IDCs accept either stranded or solid conductors and are referred to as universal or multi-purpose plugs.

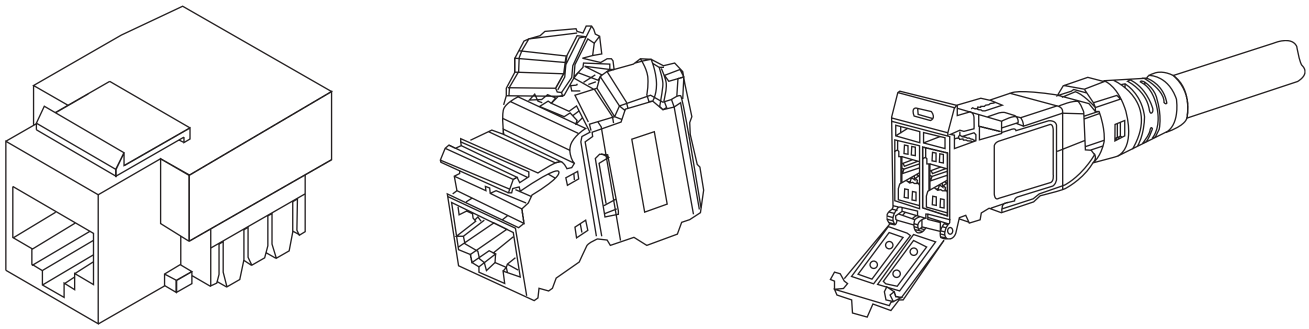
The following are the three common modular connectors used in ICT:

- 4P4C—4-position, 4-contact connectors are used primarily for telephone handset cords.
- 6P6C—6-position, 6-contact connectors are used primarily for telephones and modem line cords.
- 8P8C—8-position, 8-contact connectors are used for ICT equipment and patch cords.

Modular Twisted-Pair Connectors, continued

Modular connectors come in different forms. Three examples are shown in Figure 1.9.

Figure 1.9
Examples of balanced twisted-pair modular connectors



Unshielded connector | Shielded connector | Proprietary Category 7_A connector

Although the previous section described the characteristics of balanced twisted-pair cable transmission media, attention also should be given to the connecting hardware used to establish the entire channel. Crosstalk, signal loss, and other detriments to the performance of the network also can be attributed to these devices.

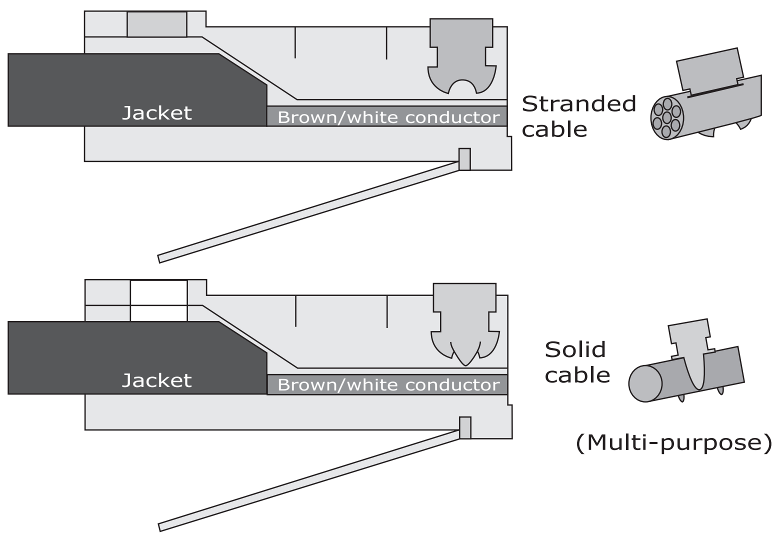
All components within a link or channel (e.g., cable, telecommunications outlet/connectors, termination methods) must have matching electrical transmission performance characteristics for a circuit to support high-speed transmissions. The installer must be aware of any specific requirements or limitations of the ICT equipment to be installed as well as the category and type of cabling required for a given application.

Modular Twisted-Pair Connectors, continued

Modular Plugs

Modular plug IPCs for stranded conductors are designed using a single blade intended to penetrate the conductors' insulation and slide between the individual conductor strands (see Figure 1.10). This type of contact should never be used with a solid conductor as the solid conductor may become nicked or broken. Damaged conductors may break and can become non-functional or subject to intermittent opens (no electrical pathway).

Figure 1.10
8-position, 8-contact (8P8C) modular plug, stranded (IPC)/solid (IDC)



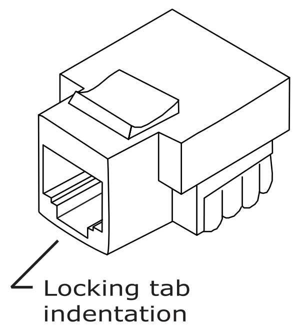
Modular plug contacts for solid conductors are designed with two or three fingers that make contact through the insulation on both sides of the conductor. The fingers provide an electrical connection by trapping the conductor between the fingers.

Modular Twisted-Pair Connectors, continued

Modular Jacks

Modular jacks are designed to connect balanced twisted-pair cables to equipment via equipment cords. The cables are terminated on the rear of the jack, while the front provides access for the 8P8C modular plug on the equipment cord (see Figure 1.11).

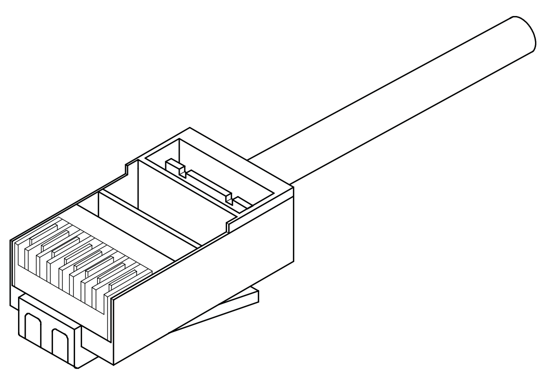
Figure 1.11
8-position, 8-contact (8P8C) modular jack



Usage

An 8P8C modular connector shall be utilized for 4-pair cable termination. Modular plugs and jacks are available in various sizes and shapes (keyed/non-keyed). The number of positions (8P) indicates the connector's capacity for conductors while the number of contacts (8C) installed into the available positions indicates the maximum number of conductors the connector can terminate. See Figure 1.12 for an example of a non-keyed 8P8C modular plug.

Figure 1.12
8-position, 8-contact (8P8C) modular plug, non-keyed



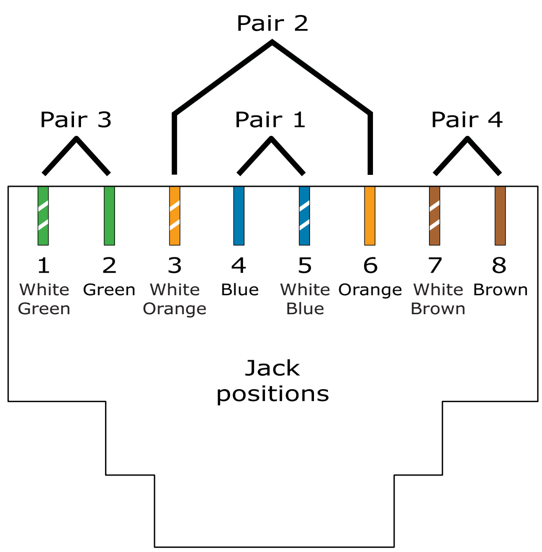
Telephone system manufacturers may supply line cords composed of 6P2C modular plugs with a 2-conductor cable. This can be a problem if the installer tries to use these cords on another type of equipment that requires more than one pair of conductors.

Modular Twisted-Pair Connectors, continued

Contact/Pin Assignments

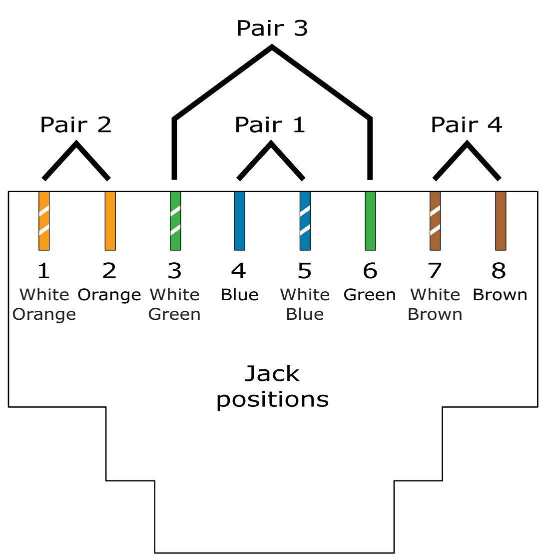
Modular connectors are capable of accepting pin assignments compatible with all known data applications operating over 100-ohm balanced twisted-pair cable. The two standards compliant wiring schemes in common use are often termed T568A and T568B. T568A is shown in Figure 1.13; T568B is shown in Figure 1.14.

Figure 1.13
T568A 8-position, 8-contact (8P8C) jack pin/pair assignments, viewed from the front



T568A

Figure 1.14
T568B 8-position, 8-contact (8P8C) jack pin/pair assignments, viewed from the front



T568B

Modular Twisted-Pair Connectors, continued

Universal Service Order Code (USOC)

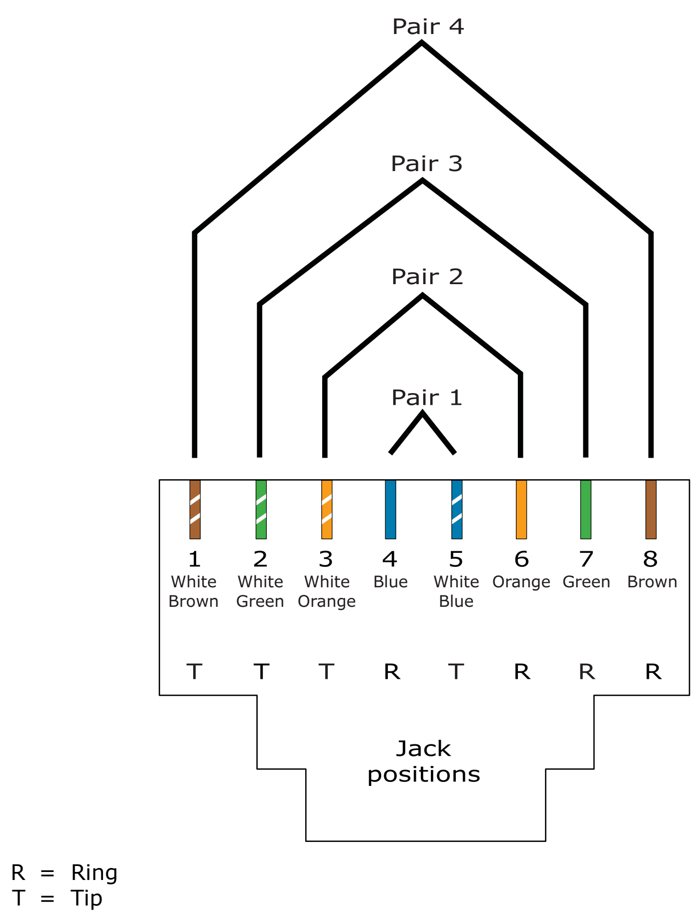
Within the United States, the Federal Communications Commission (FCC) adopted the AT&T-developed universal service order code (USOC) system that relates to all of the interface jacks used for connecting various devices to the public telephone network. Designations (e.g., RJ-21X) are used to define the physical connector as well as how the physical connector is wired.

The specific codes as adopted in part by the FCC are:

- RJ—registered jack.
- C—flush- or surface-mount jack.
- W—wall-mount jack.
- X—complex or multi-line connector.

An example of a legacy pin/pair assignment is shown in Figure 1.15. Termed RJ61, this pin/pair assignment is not suitable for network cabling applications, but may still be in use to support analog telephony applications.

Figure 1.15
Universal service order code (USOC) RJ61 pin/pair assignment, viewed from the front



Modular Twisted-Pair Connectors, continued

Screened/Shielded Twisted-Pair Connectors

Screened/shielded cabling installations require a shielding element associated with every component of the cabling system. Screen/shield continuity is maintained from the first connector in the TR to the telecommunications outlet/connector through the user's equipment cord and to the equipment's chassis ground. A metal screen/shield typically surrounds each modular connector.

Screened/shielded patch cords and equipment cords are used to extend the screen/shield from the shielded modular jacks. Each cord consists of a solid or stranded screened/shielded cable with a screened/shielded modular plug on each end. Each plug has a metal shield surrounding it. Screened/shielded cables typically include a drain wire and foil screen; both shall be terminated to the connector's screen/shield when present.

Some performance classifications of cable, typically category 7/class F and higher, require the use of shielded/screened connectors. While these cables may terminate onto a modular plug or jack, category 7/class F cabling has additional proprietary connectors available. Note that these proprietary connectors may not provide full interoperability due to each plug's different form factor.

Insulation Displacement Contact (IDC) Termination Block Hardware

The other common method of terminated balanced twisted-pair cable is with IDC termination blocks. Four common styles are in use:

- 66-style block
- 110-style block
- BIX-style block
- LSA-style block

66-Style Hardware

The 66-style IDC termination block is used for connecting voice applications (e.g., PBX, key telephone systems, some LANs). Several manufacturers of 66-style termination block designs have updated their connecting hardware to support high-speed data applications and to be compliant with category 5e/class D specifications. Caution should be used to ensure that the appropriate 66-style IDC termination block is installed in new installations.

Insulation Displacement Contact (IDC) Termination Block Hardware, continued

The 66-style termination block may be mounted on backboards with an 89-style bracket. Two different 89-style brackets are available for use. They are the 89B and 89D styles (see Figures 1.16 and 1.17).

Figure 1.16
66 Block distribution frame

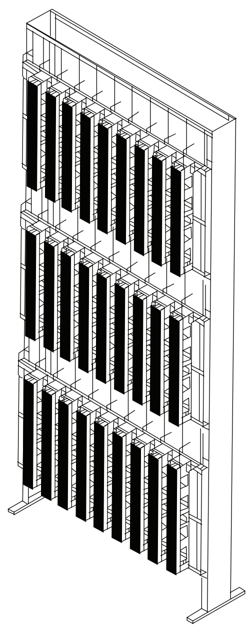
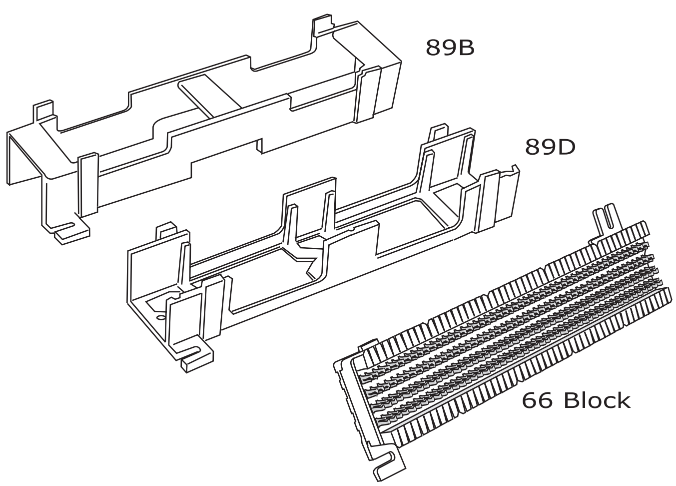


Figure 1.17
66 Block and 89 brackets



Insulation Displacement Contact (IDC) Termination Block Hardware, continued

Typically, these connecting blocks are mounted on backboards in vertical rows of four blocks each to accommodate up to 100-pair terminations. Several manufacturers provide pre-assembled single- or double-sided distribution frames to provide increments of up to 5400 pairs per side for large system installations.

Cable for a 66-style connecting block is routed through the 89 brackets to allow the pairs to be fanned out from the rear into the guides in the side of the block. Each five-pair increment is marked with a distinctive groove for ease of identification.

A 66M1-50 block provides the means of terminating two 25-pair or twelve 4-pair cables per block. These blocks have two columns of contacts that are mechanically connected to provide cross-connection capability. Voice applications use bridging clips to make a connection between the left and right sets of contacts on a 66M1-50 block. By lifting the bridging clips, which opens the circuit, it is easy to test the voice circuit in both directions when troubleshooting. The 66M1-25 blocks have four columns of connected contacts.

NOTE: Bridging clips are not category 5e/class D compliant. This description is provided for information purposes only.

A fine-tip permanent marker is generally used to designate cable-pair identifiers on the fanning strips of 66-style blocks. A potential problem with this marking method, however, is that the ink, while still wet, could accidentally be rubbed off by the installer. More suitable methods of labeling are the use of designation strips that are snapped onto the fanning strips or color-coded hinged covers that can be labeled on the inside and outside of the cover.

110-Style Hardware

The 110-style IDC termination hardware is used in both voice and data cabling applications. Backbone cabling is commonly terminated on wall- or rack-mounted 110 termination blocks in increments of 50, 100, or 300 pairs as well as on a 900-pair wall mount.

While many patch panels may be terminated in specific configurations (e.g., T568A or T568B) and mainly constructed with 110-style connectors, 110-style blocks are not designated T568A or T568B and always terminate in proper color-code order. In addition, many telecommunications outlet/connector terminations are manufactured with 110-style hardware.

Cables are routed through the middle pathway of the 110 wiring block from either the top or bottom and fanned into the wireway from alternate sides. The connecting block wireway is designed in such a way that one row is terminated on the wiring block by punching down from the bottom up. The next row is terminated from the top down. For the specific location of each termination, refer to the ICT systems designer’s layout.

Insulation Displacement Contact (IDC) Termination Block Hardware, continued

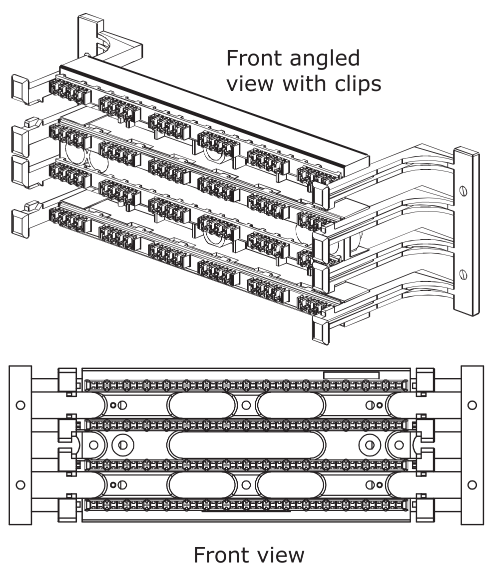
It should be noted that the 110-style wiring block itself does not contain the IDC. The IDC for this type of termination application is in the C-2 (2-pair), C-3 (3-pair), C-4 (4-pair), and C-5 (5-pair) terminating clip, or connector block, that is punched down on top of the 110-wiring block to permit cross-connection.

The terminating clip, or connecting block pair count, is determined by the application. For example, 4-pair horizontal cabling is terminated on a C-4 connecting block, and backbone cables in 25-pair increments are terminated on C-5 connecting blocks. The designation strips are then placed in the holder that covers the terminated cables.

Category 5e/class D or category 6/class E 110-style and category 6_A/class E_A 210-style wiring blocks and connecting blocks are available from multiple hardware manufacturers in varying pair configurations. This 210-style hardware features enhanced categories of performance and form factors that differ from the original 110-style systems.

Figure 1.18 shows two views of standard 110-style hardware.

Figure 1.18
110-Style hardware

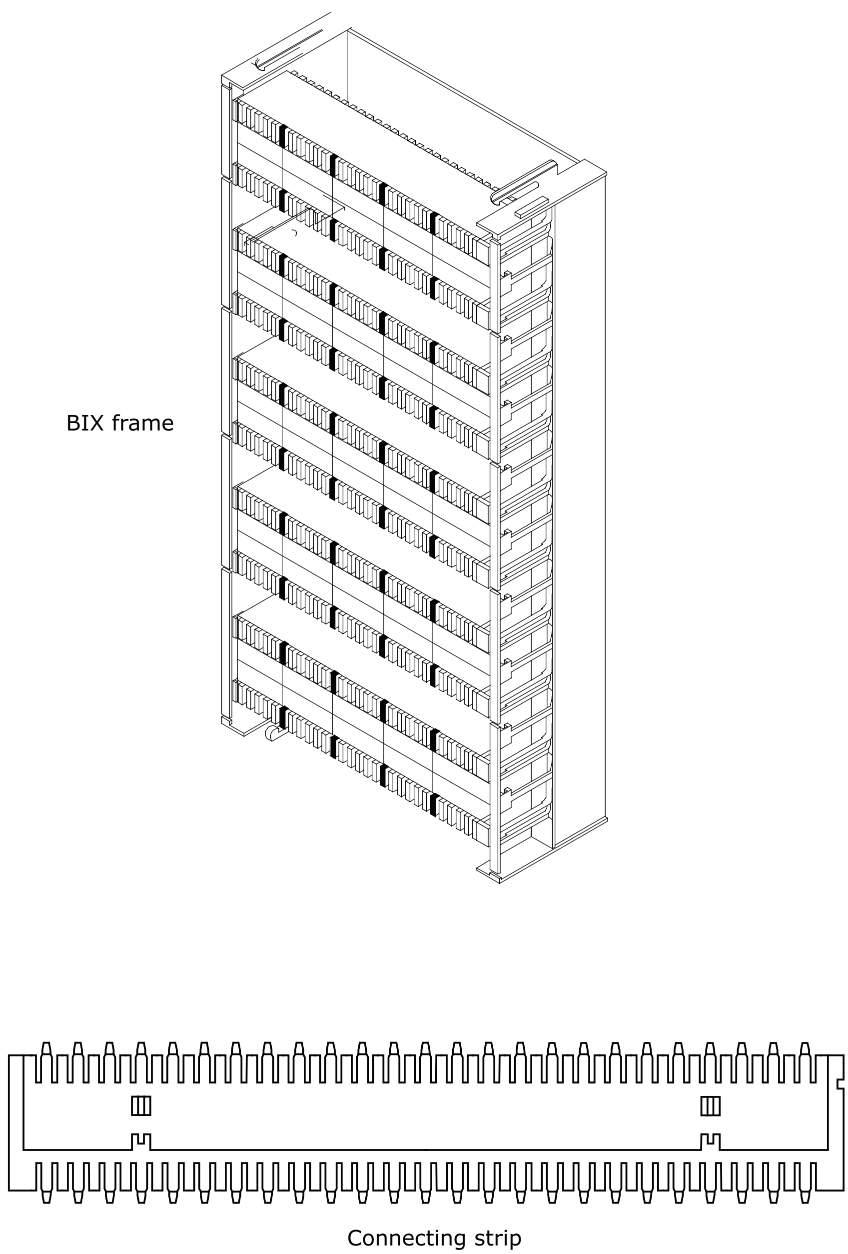


Insulation Displacement Contact (IDC) Termination Block Hardware, continued

BIX-Style Hardware

Unlike 110 hardware, which places clips on top of the wiring block, BIX equipment is a one-piece pass-through unit that is reversed in its mount after cable termination to expose the opposite side and provide a cross-connect field (Figure 1.19).

Figure 1.19
BIX frame with mounted block assemblies and BIX-style 25-pair connecting strip



Insulation Displacement Contact (IDC) Termination Block Hardware, continued

BIX termination block assemblies are available in 50-pair, 250-pair, 300-pair, and 900-pair increments for wall mounting and with floor-frame assemblies for large-size installations.

BIX-type termination hardware is available in both patch panel and telecommunications outlet/connector configurations.

BIX termination block connectors are designed with two slots for inserting small cable ties to support terminating cables. These connectors can be identified in 2-pair, 4-pair, and 5-pair increments for various applications.

When terminating cables with larger than 25 pairs on BIX termination blocks, the binder (fabric or plastic) of each of the 25 pairs should be carried to the end of the connector. The designation strips are then placed in the holder that covers the termination cable.

NOTE: When routing cables for termination, the cables must enter the mount on the side opposite from the direction that the connector will be unseated. The extra cable routed from the mount to the connector will allow the connector to be removed from the mount by hinging it to one side of the mount. The cross-connects must exit the mount on the same side that the hinge is located.

Category 6/class E GigaBIX frames and blocks do not use the hinge concept. Previously, these frames and blocks required extensive sheath removal. The newer termination technique uses less sheath removal and is similar to cable and conductor routing into the rear of a patch panel. Each 4-pair cable uses a termination bar and each wafer has a strain relief added when completed. The new frames are deeper to allow for slack management (see Figure 1.19).

Insulation Displacement Contact (IDC) Termination Block Hardware, continued

LSA-Style Hardware

LSA stands for Lötfrei Schraubfrei Abisolierfrei (no solder, no use of screws, no insulation removal) in German. LSA-style termination hardware provides silver-plated IDCs at a 45-degree angle with the conductor being held in place by tension in the contacts.

This hardware is available in patch panels, telecommunications outlet/connectors, and termination blocks. The hardware provides:

- Disconnect modules.
- Connect modules.
- Switching modules.
- Feed-through modules.

The advantage of LSA is that more than one conductor can be punched down into the same point without the risk of opening up the IDC.

Disconnect modules are normally closed, two-piece contacts that can be disconnected by inserting a disconnect plug into the wire pair. This allows temporary or permanent disconnect of the circuit. A test cord can be inserted into a pair to test circuits both ways when testing is necessary. These modules come in 8-pair and 10-pair increments.

Connect modules use a one-piece contact that provides a continuous link between the cable and the cross-connect wiring.

Switching modules consist of a normally open, two-piece contact. Switching modules allow for high-density termination and patch cables.

Feed-through modules consist of a one-piece contact that passes the signal through the module, front to back, and provides a continuous link between the feeder and the jumper for high-density termination in small areas. These modules are available in 25-pair increments.

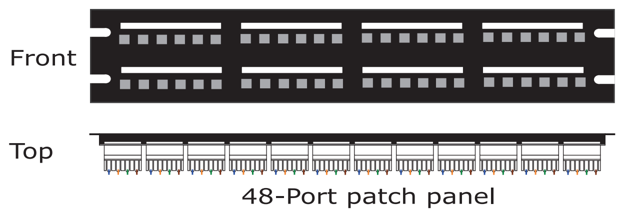
Other Termination Methods

The installer may encounter other termination methods in existing installations (e.g., binder post, screw-type, wire wrapping). These methods are not IDC types of termination and are not recommended by BICSI or industry standards for new installations of structured cabling systems (SCS). However, they may be required for replacements and expansions in existing legacy cabling systems or for use in proprietary and special purpose cabling systems.

Patch Panels

Patch panels are available from various manufacturers in many different styles and wiring configurations (see Figure 1.20).

Figure 1.20
Patch panels



Patch panels that feature 110, BIX, and LSA connections are available. Commonly used configurations are 12, 24, and 48 ports. Project specifications typically will provide count configurations and requirements.

Coaxial Cables

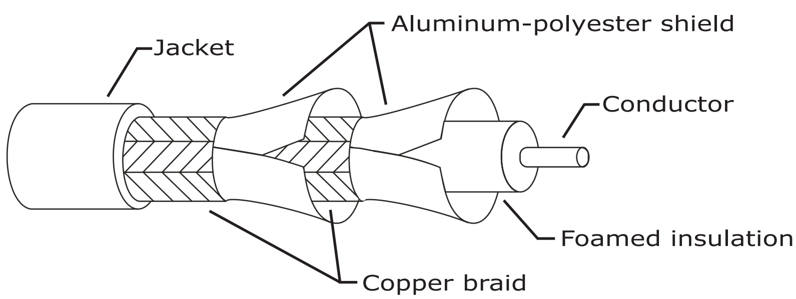
Overview

Coaxial cables have an insulated (centrally located) conductor surrounded by an overall metallic covering (see Figure 1.21). The geometry of such a construction inherently provides reduced external interference and radiation protection; however, the metallic covering is not always a shield—it can be a conductor in the circuit.

Coaxial cable is used for computer networks, community antenna TV (CATV), video systems, and wireless applications. Originally, coaxial cable was designated as radio grade (RG) cable. RG cables were originally based on military specifications and utilize a solid dielectric. Series cables have been developed using a foamed dielectric that provide improved performance compared with RG cables. Coaxial cables used in broadband applications are now referred to as Series X cables. The X designates the construction of the cable with such factors as:

- Center conductor diameter.
- Center conductor being solid or stranded.
- Dielectric composition.
- Outer braid percent of coverage (e.g., 80 or 95 percent coverage).
- Impedance.

Figure 1.21
Series-6 quad shield coaxial cable



Coaxial Cable Types

The predominant coaxial cables are Series-6 and Series-11. Both of these video cables have:

- A characteristic impedance of 75 ohm.
- Coated foil shield over the dielectric to shield against high frequencies.
- Braided shield over the coated foil to shield against low frequencies.

Series-6 coaxial cable is used for video, CATV, and security cameras. It has a solid-center conductor and BNC or F connector.

Series-11 is used in video backbone distribution. It has a solid or stranded center conductor and uses F or N connectors. It has less signal attenuation than Series-6, making it the preferred choice for longer runs.

Coaxial cables of each series are available in a variety of configurations—jacket types, shield configurations, bandwidths, and attenuations. A coaxial cable cannot be selected by simply identifying the physical size (series); a full understanding of the application is necessary, including cable listing to satisfy code and AHJ requirements.

There may be special backbone applications where a larger diameter cable is specified. While the termination procedures may be similar, special attention must be paid to the manufacturer's specific instructions for termination and connectors.

Refer to project specifications for proper cable selection. In the absence of project specifications documents, the installer should consult with the designer or a cable manufacturer's technical representative for further guidance regarding proper cable selection.

Coaxial Connectors

Either male or female connectors can be attached to coaxial cable; however, most installations use male connectors on cable ends. Use coaxial patch cables with connectors already installed when possible.

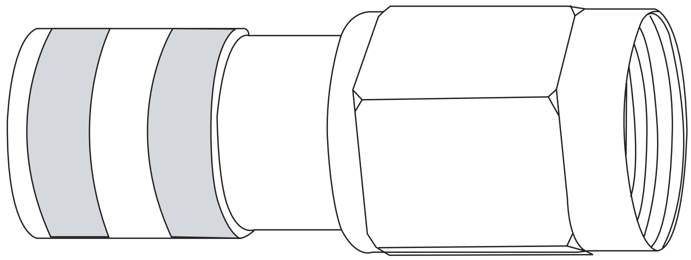
Screw-on and hex crimp coaxial connectors are not recommended for any installations and should be avoided because of their performance characteristics. Although convenient, these connectors can result in intermittent problems that can be difficult to troubleshoot.

Coaxial Connectors, continued

F Coaxial Connectors

F connectors do not have center pins. Instead, the connector uses the solid center conductor of the cable as a center pin (see Figure 1.22). For this reason, F connectors cannot be used with cables that have a stranded center conductor.

Figure 1.22
One-piece compression-style F connector



F connectors:

- Are economical.
- Are used for connecting Series-6 and Series-11 coaxial cable to video, CATV, and security cameras.
- Can be attached by compression, which provides superior sealing properties, and higher bandwidth capabilities for satellite and broadband cable installations.

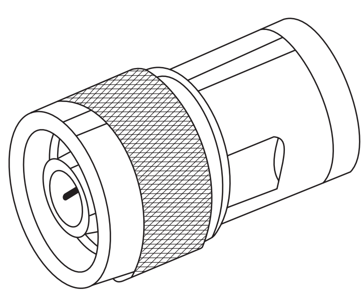
  NOTE: Require the use of a special tool that compresses the connector longitudinally rather than the traditional hex collar crimp.

While F connectors are available as a one- or two-piece crimp-on connector, these types are not recommended for use.

N Coaxial Connectors

N connectors are used in data, radio, and video applications. The connector consists of a threaded coupling nut similar in design to an F connector except it is larger (see Figure 1.23).

Figure 1.23
N connector



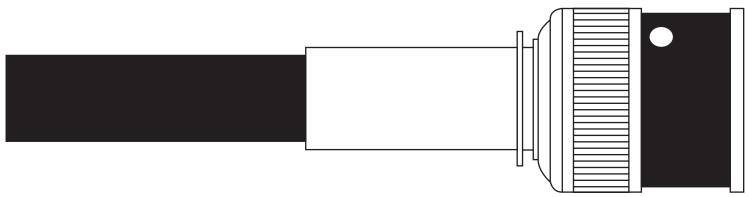
N connectors have a center pin that must be installed over the cable's center conductor. The N male connector uses a threaded outer collar to mate with the female connector.

Coaxial Connectors, continued

BNC

Named for its designers, Bayonet Neill-Concelman, the BNC connector (see Figure 1.24) has been in use since the 1940s. BNC connectors have a center pin that must be installed over the cable's center conductor and are used with RG59 (75 ohm) coaxial cable.

Figure 1.24
BNC connector (hex crimp)



Three types of BNC connectors are common:

- Three-piece crimp.
- One-piece compression (recommended).
- Screw-on (not recommended).

Compression style requires a special tool, but the center pin is captive in the connector body and does not require a separate step to crimp or solder it onto the conductor. The three-piece connector may require crimping or solder to hold the conductor to the center pin. The proper tool is especially important for obtaining an effective crimp on the sleeve of the connector.

Coaxial Cables Jacket Listing Designations

Coaxial cables support a wide variety of applications. A particular coaxial cable may be suitable for one environment or application but may not be allowed for a different application. Listed coaxial cables typically will have the applicable listing information printed or embossed on the cable jacket. When installing coaxial cable, verify that the coaxial cable to be installed is suitable for the environment and application. Refer to applicable codes (e.g., electrical code), regulations, and the AHJ for applicability and a cable substitution hierarchy.

Optical Fiber Cabling Media

Overview

Optical fiber cabling can be used in backbone and horizontal distribution applications. When high-performance network cabling is required across cabling segments greater than ≈100 m (328 ft) or an all-dielectric construction is desirable, optical fiber cabling offers characteristics that can make it the media of choice. Transmission of information through optical fiber cables is not degraded by crosstalk, lightning, and most EMI problems. However, like copper cables, attenuation (loss of signal) and physical environmental considerations are of concern for optical fiber systems.

The primary difference between balanced twisted-pair and optical fiber cabling as a transmission medium is that pulses of light consisting of photons are injected into the optical fiber as opposed to the electron flow in balanced twisted-pair cabling.

The inner portion of the glass optical fiber used for transporting the light pulse is called the core, and the surrounding glass layer is called the cladding. The purpose of the cladding is to confine the light within the core by creating a reflective boundary.

The refractive index of the core is higher than that of the cladding. Light traveling down the core, which strikes the cladding at a glancing angle, is confined within the core by total internal reflection. In other words, the cladding creates a mirror effect to reflect light back into the core that would normally escape through the outer edges of the core.

Some optical fibers use a third layer of glass, known as the trench or moat, which surrounds the core in both bend insensitive singlemode fiber and bend insensitive multimode fiber to reflect lost light back into the core. The trench is just an annular ring of lower index glass surrounding the core with carefully designed geometry to maximize the effect.

The reference used to define the size of an optical fiber is a micron (µm), a unit of measurement that is one millionth of a meter. The core size of optical fiber strands is defined in µm (e.g., 9 µm, 50 µm, 62.5 µm). The cladding size is also stated in µm (e.g., 125 µm).

Current standards support singlemode and 50/125 µm multimode optical fiber cabling. While 62.5/125 µm multimode cable was used for a number of years and has a significant installed base, 50/125 µm multimode cable has a greater bandwith, with new network installations using laser optimized 50/125 µm multimode optical fiber cable.

Optical Fiber Strands

A mode is a path of light. An optical fiber strand mode may be:

- Multimode—larger core with multiple paths of light.
- Singlemode—smaller core with only one path of light.

Singlemode optical fibers have a relatively small diameter, featuring a core typically 9 µm in diameter and a cladding diameter equal to 125 µm. Laser transmitters have a narrow light beam and can focus 100 percent of the light beam down the core of the optical fiber. Multimode has a larger core diameter (e.g., 50 or 62.5 µm) with a cladding at 125 µm. The light is restricted to a single path or mode in singlemode optical fibers, whereas the larger diameter multimode allows for many paths or modes.

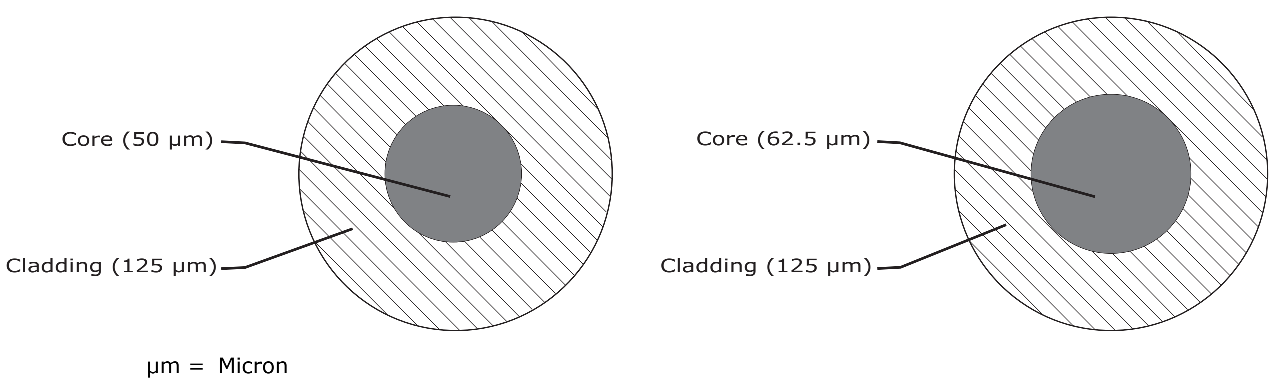
Each of these optical fiber types carries the light in different ways; therefore, they normally would not be mixed together in a single optical fiber circuit. Some exceptions (e.g., mode conditioning patch cords) are specifically designed to allow singlemode equipment to run over multimode optical fiber cables.

Multimode

Multimode optical fiber cable (see Figure 1.25):

- Is the most common for backbone and horizontal runs within buildings and campus environments.
- Has a 50 µm core and 125 µm cladding diameter. The 50 µm multimode optical fiber is available in grades of glass:
  - OM2—not recommended for new installations.
  - OM3 (laser optimized)—higher bandwidth.
  - OM4 (laser optimized)—highest multimode bandwidth.

Figure 1.25
Multimode optical fiber cable



NOTE: OM1 (62.5 µm core/125 µm cladding) is no longer recognized for new construction and should only be used when expanding an existing system composed of OM1 fiber.

Optical Fiber Strands, continued

- Has a distance limitation of ≈2000 m (6500 ft) for SCS. Be aware that supported distance are application dependent, and numerous applications are not capable of the ≈2000 m (6500 ft) limitation.
- Generally utilizes an LED light source, although vertical cavity surface emitting lasers (VCSELs) are also common.
- Supports wavelengths of 850 nanometers (nm) and 1300 nm.

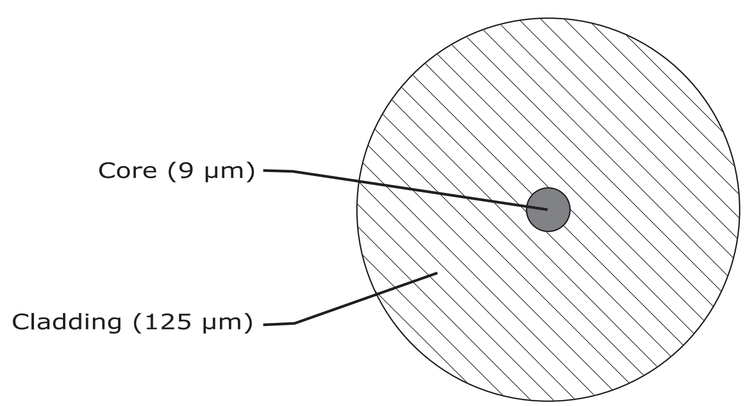
Singlemode

Singlemode optical fiber cable (see Figure 1.26):

- Is used in horizontal, riser, and campus environments.
- Has a 9 µm core:
  - OS1—LAN, typically tight-buffered construction
  - OS2—Outside plant (OSP), typically loose-tube construction
- May be used for distances up to ≈3000 m (9842 ft) for SCS:
  - Distances supported are application dependent.
  - Some applications can exceed the ≈3000 m (9842 ft) restrictions placed on an SCS.
- Normally uses a laser light source.
- Wavelengths typically supported:
  - OS1: 1310 nm, 1550 nm
  - OS2: 1310 nm, 1490 nm, 1550 nm, and 1625 nm

Singlemode optical fiber systems are frequently used for long-haul transmission systems, data systems requiring high bandwidth, and many optical fiber-based video distribution systems.

Figure 1.26
Singlemode optical fiber cable



µm = Micron

Cable Construction

Optical fiber cable types can include:

- Simplex (single fiber strand):
  - Zip cord (looks like the electrical cord found on small appliances and lamps; dual strands each with ≈3 mm [0.12 in] jackets [typical] that are bonded together). Many duplex patch and equipment cords use zip cord construction.
- Tight buffered (fiber strands with a 900 µm buffer coating):
  - Distribution (multiple 900 µm tight-buffered strands under a single jacket).
  - Breakout (multiple ≈2 mm [0.08 in] through ≈3 mm [0.12 in] subunits individually jacketed strands under a single overall jacket). Larger diameter compared with distribution cable because each 900 µm strand is built up to an ≈2-3 mm (0.08–0.12 in) jacketed subcable.
- Loose tube (multiple tubes containing multiple ribbons or multiples of individual 250 µm buffered fibers):
  - Central tube (loose-tube construction with a single tube containing multiple ribbons or multiples of individual 250 µm buffered fibers).
- Ribbon (multiple 250 µm fibers bonded into a flat, color-coded ribbon).
- Air-blown optical fiber (fibers designed to be installed with compressed air or nitrogen through specially designed tubular microduct assemblies).

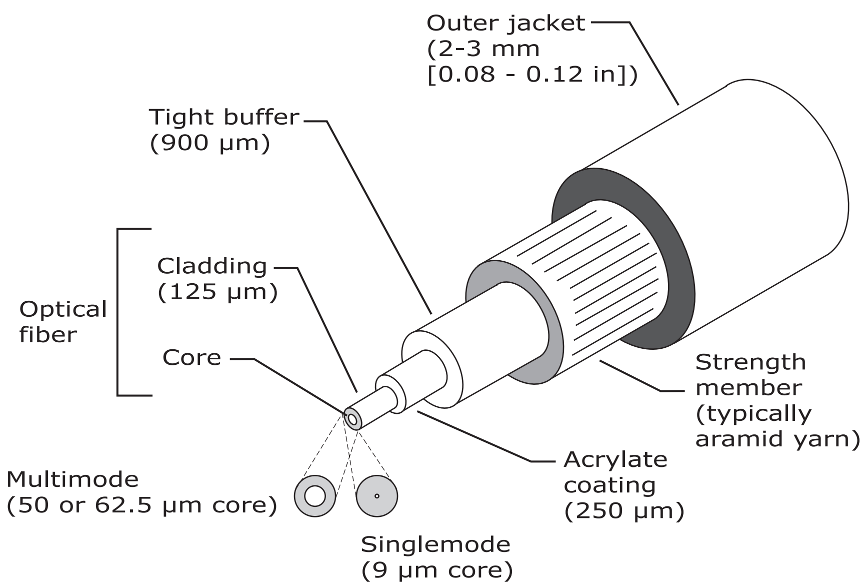
Cable Construction, continued

Tight-Buffered Optical Fiber Cable

Tight-buffered optical fiber cable (see Figures 1.27 through 1.29):

- Is primarily used inside buildings. (It may contain water-blocking materials for use outside of a building.)
- Is available with various jacket types to meet building codes.
- Protects the optical fiber by supporting each strand of glass with a buffer coating extruded over the base optical fiber's 250 µm acrylate coating. The most common tight-buffer diameter is 900 µm although other diameters are available.
- Is easily connectorized.
- May be singlemode or multimode.

Figure 1.27
Single-stranded tight-buffered optical fiber cable



µm = Micron
in = Inch
mm = Millimeter

Cable Construction, continued

Figure 1.28
Tight-buffered optical fiber cable, distribution design (12 strand)

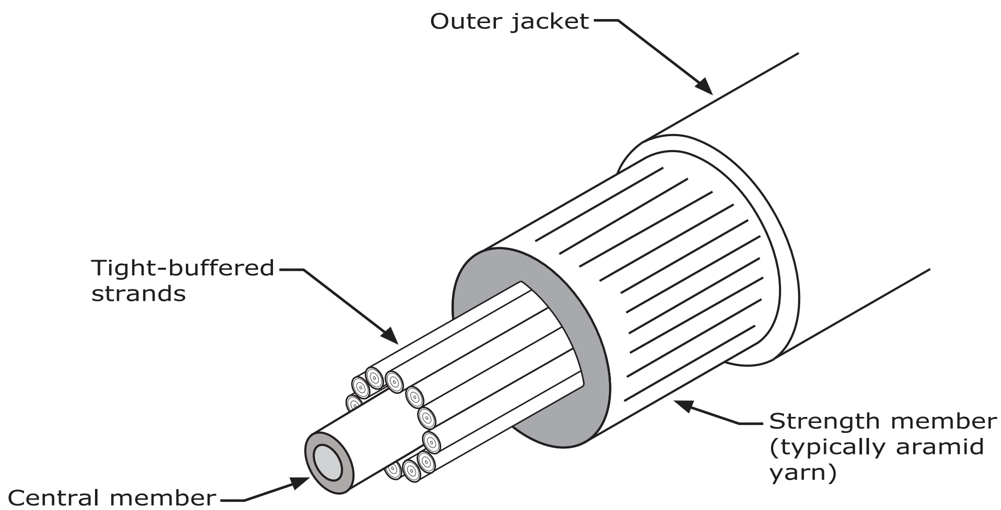
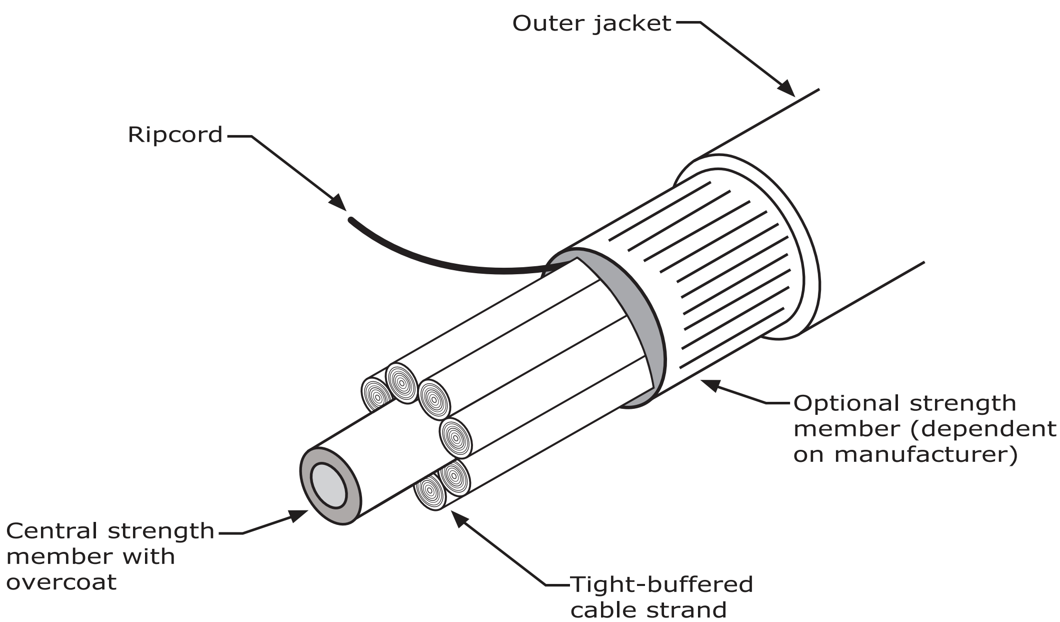


Figure 1.29
Tight-buffered optical fiber cable, breakout design (8 strand)



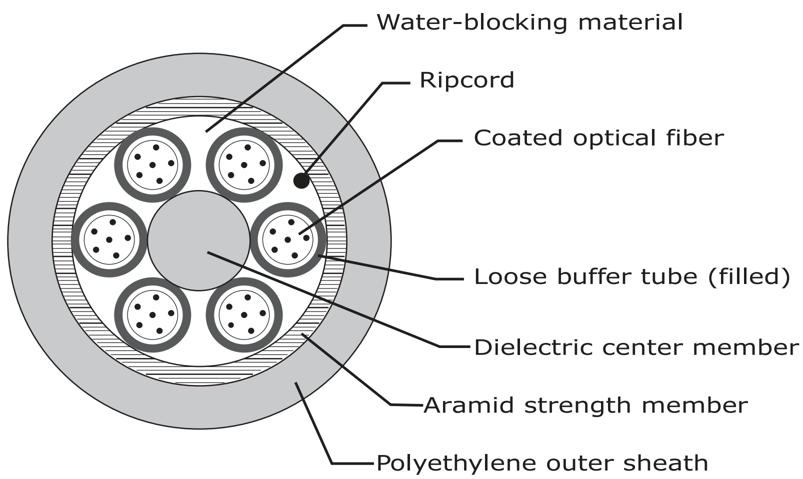
Cable Construction, continued

Loose-Tube Optical Fiber Cable

Loose-tube optical fiber cable (see Figures 1.30 and 1.31):

- Is used primarily outdoors (e.g., external to a building or utilizing OSP pathways and spaces).
- May contain water-blocking material (water absorbent tapes that swell when exposed to moisture or water-blocking gels).
- Allows the cable jacket to expand and contract with changes in temperature without affecting the fibers.
- Has a shorter cable jacket length to the fiber length inside (helix factor).
- May be singlemode or multimode.
- Often uses loose-tube optical fiber with a diameter of 250 µm although other diameters are available.
- May require furcation tubing (see Figure 1.32) or fan-out kits to build up the fiber strand's diameter to allow direct connectorization.

Figure 1.30
Loose-tube optical fiber cable



Cable Construction, continued

Figure 1.31
Side view of a loose-tube optical fiber cable

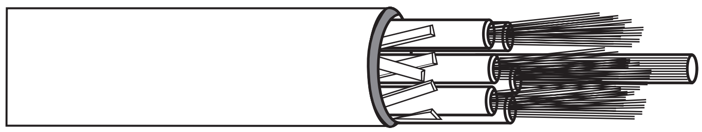
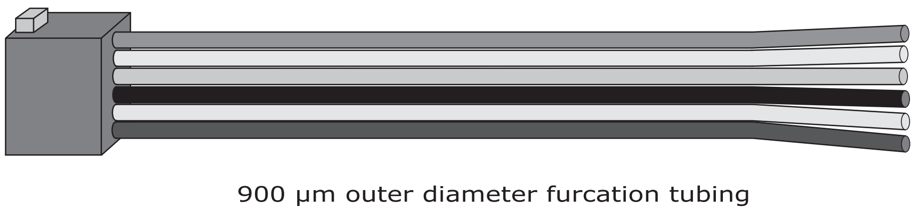


Figure 1.32
Loose-tube furcating harness



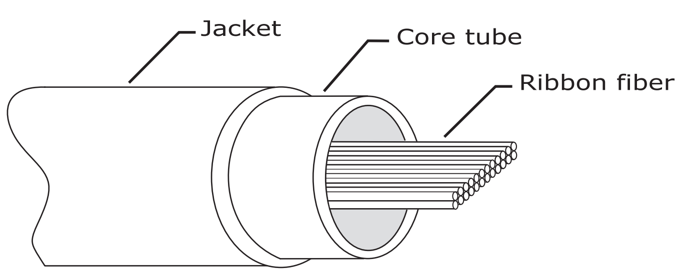
µm = Micron

Ribbon Optical Fiber Cable

Ribbon optical fiber cable (see Figure 1.33):

- Can be used indoors and outdoors.
- Consists of up to 24 strands bundled together in a single line of color-coded ribbon.
- May have multiple ribbons within buffer tubes that provide high optical fiber counts in a small diameter cable.
- May consist of singlemode, multimode, or a combination of the two.
- Can be quickly spliced when using special equipment (e.g., mass fusion).
- Uses array connectors (multifiber push-on [MPO]).

Figure 1.33
Ribbon optical fiber cable



Cable Construction, continued

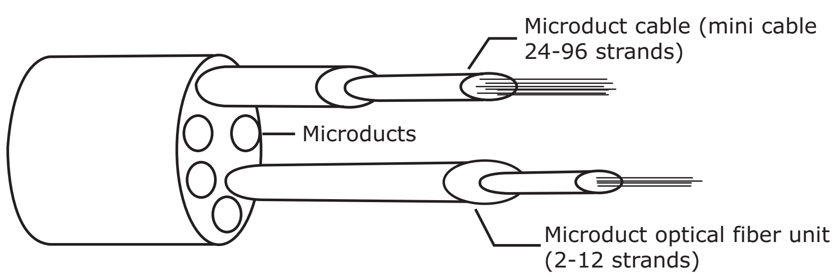
Air-Blown Optical Fiber Cable

Air-blown optical fiber systems consist of specialized pathways and optical fiber assemblies. An infrastructure of flexible tubing is installed between telecommunications spaces and connected to an enclosure that allows for the interconnection of tubes to create a continuous pathway for the specialized fiber to be blown through. Air-blown optical fiber systems utilize microduct optical fiber cables, microduct fiber units, microducts, and protected microducts (see Figure 1.34).

During the operational lifetime of an air-blown optical fiber cable, it is possible to add or remove the microduct optical fiber cable or microduct fiber unit in or from the microducts. When considering recovering a product for potential reuse, care must be taken to minimize stress on the product and ensure that the product is carefully handled and packaged in accordance with the manufacturer's guidelines.

NOTE: Industry best practice is to test all previously recovered products adequately before they are redeployed.

Figure 1.34
Air-blown optical fiber cable



Cabling Performance Classification

Two characteristics of particular importance in the transport of information over optical fiber media are bandwidth and attenuation. Bandwidth and attenuation relate to the transmission of light pulses over optical fiber cables.

Tables 1.9 and 1.10 show the minimum bandwidth (capacity) and attenuation (insertion loss) per kilometer for each of the most commonly used optical fiber types.

Table 1.9
Optical fiber cable bandwidth performance parameters

	Multimode	850 nm OFL	850 nm RML	1300 nm	1310 nm	1550 nm
FDDI	62.5/125 µm	160 MHz•km	N/A	400 MHz•km	N/A	N/A
OM1	62.5/125 µm	200 MHz•km	N/A	500 MHz•km	N/A	N/A
OM2	50/125 µm	500 MHz•km	N/A	500 MHz•km	N/A	N/A
OM3	50/125 µm Laser optimized	1500 MHz•km	2000 MHz•km	500 MHz•km	N/A	N/A
OM4	50/125 µm Laser optimized	3500 MHz•km	4700 MHz•km	500 MHz•km	N/A	N/A

µm = Micron
FDDI = Fiber distributed data interface
km = Kilometer
MHz = Megahertz
N/A = Not applicable
nm = Nanometer
OFL = Overfilled launch
OM = Optical multimode
RML = Restricted modal launch

NOTE: The terms overfilled launch and restricted modal launch relate to the method of presenting the light into the optical fiber from the active equipment.

Cabling Performance Classification, continued

Table 1.10
Optical fiber cable attenuation performance parameters

	Multimode	850 nm	1300 nm	1310 nm	1550 nm
OM1	62.5/125 µm	3.5 dB/km	1.5 dB/km	N/A	N/A
OM2	50/125 µm	3.5 dB/km	1.5 dB/km	N/A	N/A
OM3	50/125 µm Laser optimized	3.5 dB/km	1.5 dB/km	N/A	N/A
OM4	50/125 µm Laser optimized	3.5 dB/km	1.5 dB/km	N/A	N/A
OS1/LAN	8.3/125 µm	N/A	N/A	1.0 dB/km	1.0 dB/km
OS2	8.3/125 µm	N/A	N/A	0.5 dB/km	0.5 dB/km

µm = Micron
dB = Decibel
km = Kilometer
N/A = Not applicable
nm = Nanometer
OM = Optical multimode
OS = Optical singlemode

Optical Fiber Cable and Strand Color Codes

There are standards that cover the color coding of optical fiber cables (e.g., TIA-598-C). Where there is no applicable standard, the cable manufacturer will determine the color sequence and grouping of the fibers. It may be that two different sources of cable are used on a project, which means there may be a different color code for the fibers of each cable. The installer should map out the color code and document which fiber is joined or terminated at each point in the channel.

Cabling Performance Classification, continued

An example of a cable color standard is as follows (see Table 1.11):

- Strands 1 to 12 shall be uniquely color coded.
- Strands 13 to 24 shall repeat the same color code as 1 to 12 with the addition of a black tracer.
- The black tracer may be a dash line or a solid line.
- The black strand has a yellow tracer.

Table 1.11
Optical fiber color code chart

Optical Fiber	Optical Fiber Color	Color Number	Color Tracer
1	Blue	13	Blue/black tracer
2	Orange	14	Orange/black tracer
3	Green	15	Green/black tracer
4	Brown	16	Brown/black tracer
5	Slate	17	Slate/black tracer
6	White	18	White/black tracer
7	Red	19	Red/black tracer
8	Black	20	Black/yellow tracer
9	Yellow	21	Yellow/black tracer
10	Violet	22	Violet/black tracer
11	Rose	23	Rose/black tracer
12	Aqua	24	Aqua/black tracer

Optical fiber cables larger than 24 strands are color coded by means of binder tapes, ribbons, or threads consisting of two binders—one to match the base color and one to match the tracer color. Refer to the manufacturer's specific color scheme for details.

Cabling Performance Classification, continued

While it may seem that the majority of interior optical fiber cables have orange jackets, there is no mandatory standard to identify the color coding for optical fiber jackets (see Table 1.12).

NOTE: Compliance to the color code is voluntary; many manufacturers do not follow the standard-based recommendations.

Table 1.12
Color coding of outer cable sheaths

Cables with Optical Fiber Type	Color of Sheath
Singlemode optical fiber	Yellow
Multimode optical fiber with 50 µm core diameter	Orange
Multimode optical fiber with 50 µm core diameter (laser-optimized)	Aqua
Multimode optical fiber with 62.5 µm core diameter	Orange
Multimode optical fiber with 100 µm core diameter	Orange
Dispersion-shifted singlemode optical fiber	Red
Polarization maintaining singlemode optical fiber	Blue

µm = Micron

Optical Fiber Cable Jacket

The cable jacket on an optical fiber cable serves two main functions for the fibers in the cable:

- Physical protection
- Environmental protection

Physical protection is provided through the cable design and the use of yarns that run alongside the fiber strands in the cable and the materials used in and around the cable's jacketing. Physical protection is also provided by using different materials for the jacket layers (e.g., glass reinforced plastic rods, corrugated steel tape under the cable's jacket, external steel wire armor).

Environmental protection is provided through the choice of materials in the cable jacket and filler materials used inside the cable. The choice of materials used in the jacketing and insulation depends on UV protection for OSP installations and fire ratings for listing a cable suitable for intrabuilding installations. The materials used inside the cable could include water-blocking gel or tapes to stop migration of water along the inside of the cable.

Gel is used to fill or flood a cable to displace any water that may try to enter the cable. When the tapes are exposed to moisture, they swell and fill the voids within the cable and block the moisture from traveling. Various materials are used for fire rating of the jacket for the application (e.g., polyvinyl chloride, plenum, low smoke zero halogen).

Optical Fiber Cable Jacket, continued

The cable marking types presented in Table 1.13 for optical fiber cable are used when deciding which cable type is appropriate for the space being cabled. The table does not represent a cable substitution hierarchy, and they do not show all possible cable markings. Refer to applicable codes, standards, and regulations for such cable substitution hierarchy.

Table 1.13
Optical fiber cable listing designations and communications raceway (innerduct)

Cable Marking	Type
OFNP	Non-conductive optical fiber plenum cable
OFCP	Conductive optical fiber plenum cable
OFNR	Non-conductive optical fiber riser cable
OFCR	Conductive optical fiber riser cable
OFNG	Non-conductive optical fiber general-purpose cable
OFCG	Conductive optical fiber general-purpose cable
OFN	Non-conductive optical fiber general-purpose cable
OFC	Conductive optical fiber general-purpose cable
LSZH (LSF)	Low smoke zero halogen (low smoke and fume)

Optical Fiber Cabling Properties

Bandwidth

The modal bandwidth of an optical fiber provides a measure of the amount of information an optical fiber is capable of transporting. Modal bandwidth is described in terms of MHz•km.

Increasing either the length of the cable or the wavelength of the light source decreases the modal bandwidth and, therefore, the information-carrying capacity of the transmission path.

Dispersion

Dispersion is the widening or spreading out of the modes in a light pulse as it progresses along the optical fiber. If the pulse widens too much, it can overlap at the receiver and make it impossible to distinguish one pulse from another. As errors occur in the reading of pulses (bits), the bit error rate (BER) increases. Therefore, bandwidth is limited by total dispersion (i.e., the sum of modal dispersion and chromatic dispersion).

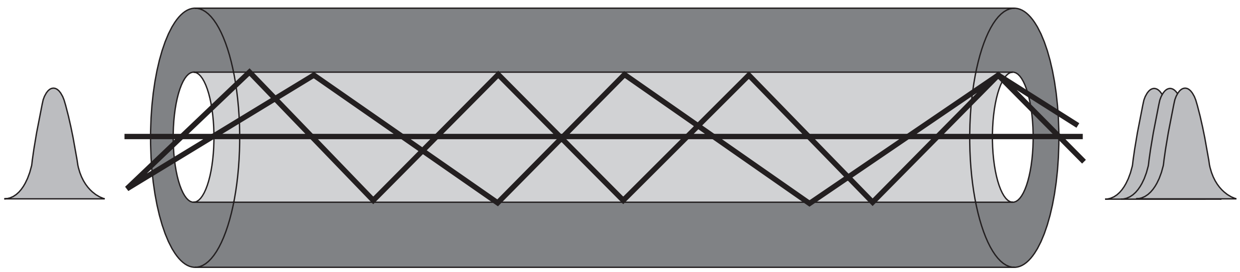
Optical Fiber Cabling Properties, continued

Modal Dispersion

Modal dispersion results from the different optical path lengths in a multimode fiber (see Figure 1.35).

It is also called modal distortion. It is characteristic of the transmission in an optical fiber that results from different lengths of the light paths taken by the many modes of light as they travel down the fiber from the source to the receiver.

Figure 1.35
Modal dispersion



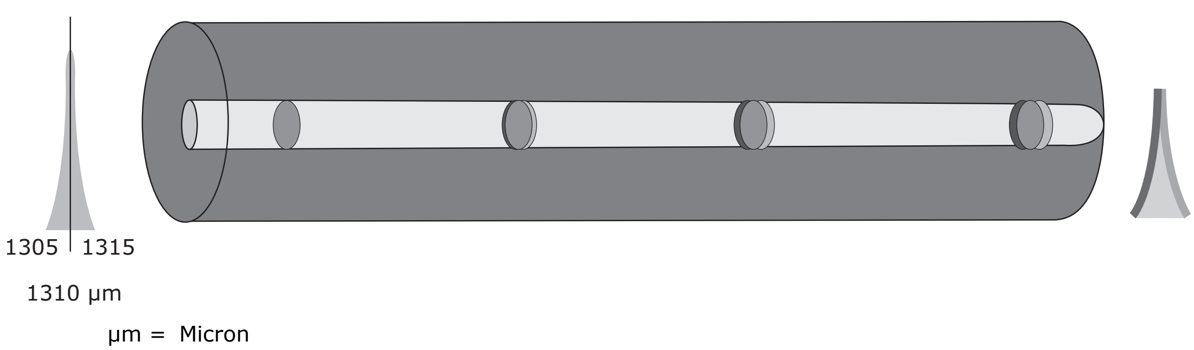
Chromatic Dispersion

Chromatic dispersion begins at the light source (see Figure 1.36). The sources utilized to create the light pulses are either a laser, VCSEL, or LED and do not furnish a perfectly monochromatic (single wavelength) light. Thus, the light injected into the optical fiber media contains a number of slightly differing wavelengths.

Because the index of refraction of the glass optical fiber is not the same for different wavelengths, each travels through the optical fiber at a slightly different speed.

Modal dispersion tends to further broaden these pulses. Together, these dispersion factors increase the BER and lower the effective bandwidth. Through the use of graded index optical fiber, the effects of modal dispersion are reduced but are not eliminated.

Figure 1.36
Chromatic dispersion



Optical Fiber Cabling Properties, continued

Attenuation

Light pulses in optical fiber cables are subjected to a loss in power as the light pulses travel along the optical fiber. This attenuation occurs as a result of absorption of power by impurities within the glass itself and scattering of the light.

Losses because of scattering are caused by such factors as:

- Dopants and impurities in the glass material.
- Core size variations (different manufacturers may have slight variations in core diameters).
- Variations in the interface between the core and cladding.
- Macrobends and microbends in the strands.
- Concentricity (relationship of core and cladding that make up the optical fiber).

Optical fiber attenuation is referenced in decibels per kilometer. It is proportional to length and is affected by the wavelength of the light contained in the pulse.

The mishandling of optical fiber cable during installation or improper termination of optical fiber cable is frequently the cause of most unexpected attenuation. To provide a fully functional optical fiber transmission system:

- Maintain adequate bend radii per the manufacturer’s or standard’s specifications.
- Use cable designed for the environment.

Bend insensitive cable is designed to have minimal attenuation increase when being bent beyond the capabilities of non-bend insensitive fibers. They typically can be bent 10 times tighter than non-bend insensitive fibers with similar amounts of attenuation. Bend insensitive fiber adds a third layer of glass between the core and the cladding of the fiber, which has a lower index of refraction than the core that reflects the weakly guided modes back into the core.

Connectors

Connectors provide certain critical functions, including:

- Minimizing power loss when mating to other cables or equipment.
- Securing optical fiber retention within the connector.
- Securing connector retention within equipment or adapter.
- Protection for the end of the optical fiber.
- The ability to connect to and disconnect from other cables or equipment.

Two important qualities of a connector are the ability to:

- Latch securely.
- Connect to other cables or equipment with low loss.

Connectors, continued

This is achieved by the connector mechanism, which usually consists of a:

- Ferrule (flat or pre-radiused end).
- Key (assures consistent connector orientation within adapters/couplers).
- Latching ring or latching mechanism.

The three groups of connectors for optical fiber cable are:

- Single/double strand connectors (present usage).
- Array (ribbon) optical fiber.
- Legacy types.

Single/Double Strand Connectors (Present Usage)

Connectors presently used within optical fiber cabling systems include:

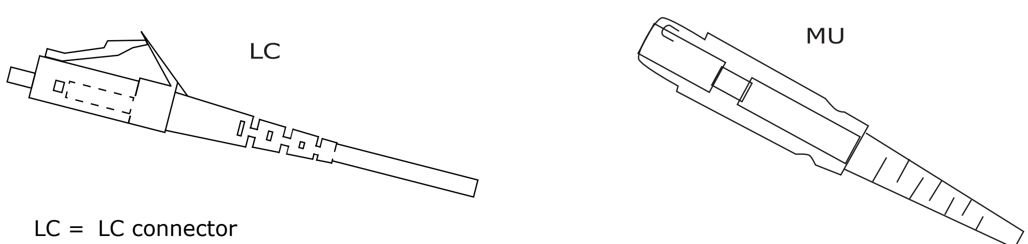
- Straight tip (ST) compatible—a keyed, contact, moderate loss connector (not pull or wiggle-proof).
- Subscriber connector (SC)—a keyed, contact, moderate loss connector (pull and wiggle-proof).
- Small form factor (SFF)—a smaller connector that allows higher density of connectors in patch panels and equipment ports.

Some common SFF connectors (see Figure 1.37) are:

  – LC—A simplex connector that can be converted to a duplex configuration using two connectors and a clip to create a keyed duplex connector assembly. It is keyed, contact, low loss, pull, and wiggle proof. This multiple use connector can be terminated many different ways, including quick cure adhesive, cleave and crimp, and hot melt.

  – MU—A simplex connector that resembles an SC, but the dimensions are one-half the size of the SC. It is keyed, contact, moderate loss, pull, and wiggle proof. This multiple use connector can be assembled as a duplex, triplex, or quadruple connector.

Figure 1.37
Common small form factor (SFF) connectors



LC = LC connector
MU = MU connector

Connectors, continued

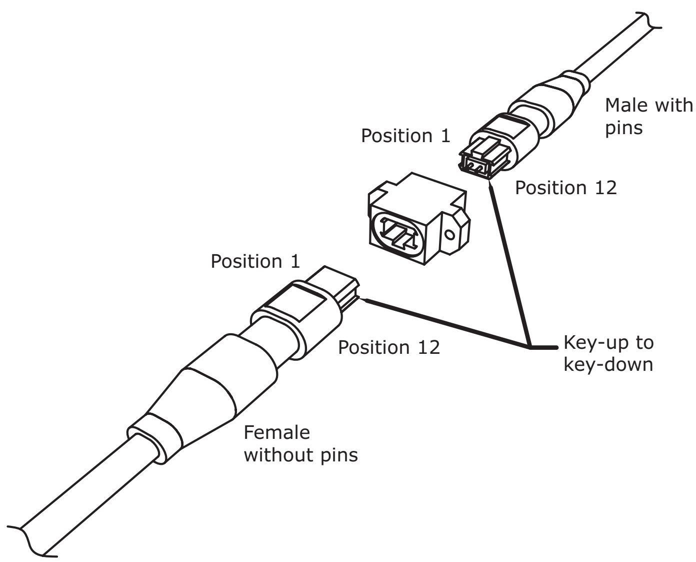
Array Connectors

Array connectors terminate 6 to 72 optical fibers in a single ferrule.

Array connectors may be used to connect to equipment in data centers or pre-wired optical fiber cassettes. These connectors often are pre-terminated at the factory. MPO is an example of a high-density optical fiber connector.

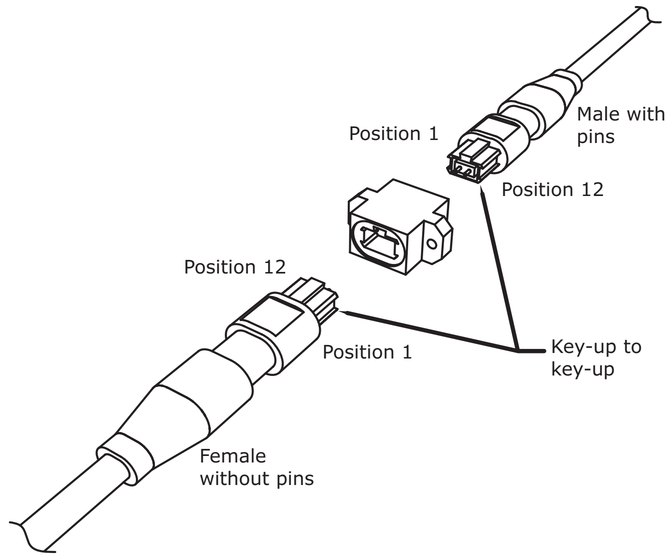
Figures 1.38 and 1.39 demonstrate array optical fiber connectors with alignment pins. The individual optical fibers between the alignment pins are not visible in these figures. The array optical fiber adapter provides a means for coupling two array optical fiber connectors.

Figure 1.38
Example of Type A multifiber push-on (MPO) configuration



Connectors, continued

Figure 1.39
Example of Type B multifiber push-on (MPO) configuration



Legacy-Style Connectors

Some connectors are rarely used today but may be present in legacy systems. Three legacy-style connectors include:

- Subminiature version A (SMA) 905.
- SMA 906.
- Biconic.
- Enterprise systems connection.
- Fiber distributed data interface, media interface connector.
- Fiber connector.
- Mechanical transfer RJ.
- Opti-jack.

Connectors, continued

Coupling of Optical Fibers

There are two ways to connect two fibers together:

- Plug-to-plug:
  - Each fiber is connectorized with a male connector. A female optical adapter/coupler is used to interface the two male connectors together (e.g., a patch panel or work area faceplates with female adapters/couplers are used to join a cable installed into the rear of the panel to a patch cord plugged into the front of the panel).
- Plug-to-jack:
  - One of the fibers is connectorized with a female jack. The jack can then be snapped into a patch panel or faceplate.
  - The second cable is connectorized with a male plug. The male plug is then inserted into the female jack. The female adapter used in the plug-to-plug arrangement is not needed in a plug-to-jack configuration.

Optical Fiber Hardware

The purpose of hardware is to protect and provide organization for cables, splices, and connectors. Optical fiber hardware includes the following:

- Closures—used to protect splices.
- Enclosures—may be rack or wall mounted and they are used to organize cables, optical fiber strands, splice trays, and connectors.
- Housings—the same as enclosures but typically only mount in equipment racks.
- Trays—the same as housings but are usually only one rack unit in height.

Enclosures, housings, and trays may be configured to hold:

- Cable strand routing hardware.
- Individual or duplex connector adapters/couplers for creating a patch panel.
- Fiber subpanels or cassettes where groups of connector adapters/couplers are installed to create patch panels that offer denser population of optical strands.
- Various cassettes that may offer pigtail splicing or MPO to LC, SC, or SC transitions (e.g., one backbone 12-strand MPO transitioning to 12 LC connectors for cross-connecting on the front of the panel, one backbone 72-strand MPO transitioning to six 12-strand MPO on the front of the panel).

Appendix: Codes, Standards, and Regulations

Overview

Since the advent of the telegraph, codes, standards, and regulations have been adopted to define the safe production, installation, and use of ICT systems. Nothing impacts the design and construction of a telecommunications network more than codes, standards, and regulations.

Designers and installers must be familiar with the electrical, communications, safety, and building codes, standards, and regulations for the nation, region, and municipality in which the design and installation work is performed. Designers and installers must also be aware of the critical importance of compliance with codes, standards, and regulations.

Design and Construction

In the United States, Canada, and most other countries, building codes and standards regulate the design and construction industry. Installation methods and products must conform to local regulatory, code, and standards requirements. The local AHJ normally enforces the codes and legal regulations for the jurisdiction.

Designers and installers must have a thorough knowledge of the applicable sections of these codes that affect telecommunications. Be aware that these codes and standards are updated regularly. It is the responsibility of the designer and installer to follow the changes and comply with the current codes and standards that are in effect within the applicable jurisdiction.

Codes, Regulations, and Directives

A code can be defined as "a rule or set of rules intended to ensure safety during the installation and use of materials, components, fixtures, systems, premises, and related subjects."

Codes typically are invoked and enforced through government regulation. A code ensures the:

- Practical safeguarding of persons and property from hazards.
- Quality of construction.

Codes typically pertain to a construction trade (e.g., electricity, building, fire) and may cover other safety issues.

For the ICT installer, the code most often encountered is the electrical code. The *National Electrical Code®* (*NEC®*) in the United States and the *Canadian Electrical Code* (*CEC*) in Canada are issued to provide the criteria for minimizing the risk of electrical shock, fires, and explosions from electrical installations.

Once a code is adopted or ratified by a government or other formally authorized body, it can be legally enforced by an AHJ. An AHJ may be a specific code authority (e.g., electrical inspector, building inspector, fire marshal). Typically, more than one AHJ will be involved on the project site because of different aspects requiring review and approval. The designer and installer must meet and comply with specific code requirements and concerns.

State, provincial, municipal, and local codes may be more restrictive than national codes and regulations and, therefore, take precedence. The order or hierarchy of code compliance should be in full conformance to local, state, and national codes.

In the European Union (EU), a set of regulations titled directives take precedence. Some examples of these regulations are the European Union Construction Products Regulation (305/2011 EC) and the Electromagnetic Compatibility Directive (2014/30/EU).

Within each country, building regulations and other government-mandated regulations are enforced.

State Regulations

At the state level in the United States, many governmental bodies, such as public utility and service commissions, issue their own rules. State rules are generally in accordance with FCC regulations.

The state commissioned rules are available to the public. Certain sections of these rules deal with installing telecommunications cabling and cable facilities on private and public property.

Municipal/County/Local Regulations

Other regulations that may affect the installation of ICT systems include:

- Licensing
- Permitting

These may involve additional costs or fees within the state or municipality in order to meet the criteria for implementation of the project.

Special Applications

Designers and installers must be aware of any special restrictions or conditions in specialized environments such as:

- Manufacturing and industrial areas:
  - Hazardous environments.
  - Corrosive environments (e.g., chemicals).
  - Explosive and combustible material environments.
  - Electromagnetic systems, radio frequency systems, and electromagnetic compatibility (EMC) environments.
- Life safety areas:
  - Health care facilities.
  - Public safety access points.
- Government, military, and other secure facilities.
- Natural environments:
  - Seismically active.
  - Flood zones.

Standards

A standard is an accepted collection of requirements and recommendations for the defining, construction, evaluation, application, or comparison of materials, equipment, products, and services. Standards may define processes, procedures, practices, or methods and are developed to improve the quality, function, performance, repeatability or some other facet of the item being defined. A standard is typically developed and approved by consensus or a group of individuals, and may be developed by entities such as businesses, industry groups, or governments. Compliance to a standard is a voluntary act, unless otherwise specified by law, contract, or other binding article.

One of the purposes of a standard is to ensure a minimal level of acceptable performance. While codes and safety standards address the safety of persons and property in the installation or use of a system, codes do not ensure the system functionality.

NOTE: Codes may reference numerous standards to ensure the minimum functional requirements of a given material or component.

Safety standards provide the criteria for safety testing of a component or system. Performance and safety standards are typically test standards. Test standards provide uniform rules for the object, methods, and acceptable results of testing. For example, UL 1479, *Fire Tests of Through-Penetration Firestops*, defines a number of test methods to determine the performance of a firestop assembly during a fire.

This listing is given to the material that meets a specific safety test standard of minimum acceptable requirements for:

- Flammability.
- Smoke generation.
- Smoke density.
- Amount of toxic gasses generated under flame.

Other standards are not written for safety requirements, but they are written for product performance or conformance.

As with most standards, telecommunications, ICT, and ESS standards are typically voluntarily adopted. They represent industry consensus on requirements and best practices. A significant benefit of standards in the telecommunications industry is the ensured interoperability of components and systems by multiple manufacturers.

For example, if a manufacturer of network interface cards (NICs) does not adhere to standards such as IEEE 802.3, then the product may not properly function with other standards-compliant products.

Standardization Efforts

United States (U.S.) Standards Development

In 1988, the telecommunications sector of the Electronic Industries Association (EIA) became the Telecommunications Industry Association (TIA). TIA conducted the standards activities through EIA until it no longer needed its sponsorship for national standard recognition. Current standards no longer carry the EIA endorsement.

Most TIA standards that govern telecommunications cabling infrastructure are accredited through the American National Standards Institute (ANSI). As such, they have a broad industry acceptance throughout the United States.

Associations, such as the Alliance for Telecommunications Industry Solutions (ATIS), BICSI, and the Society for Cable Telecommunications Engineers (SCTE), have developed standards that further define aspects of telecommunications, ICT, cable TV, and ESS cabling, cabling design, and cabling installation.

International Standards Development

The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) jointly oversee international standardization of telecommunications cabling. These organizations form a specialized system for worldwide standardization.

National bodies that are members of the ISO or IEC participate in the development of international standards through committees that deal with specific technical fields. ISO and IEC committees collaborate with other international governmental and non-governmental organizations to develop harmonized international requirements.

In the field of information technology, ISO and IEC have established a joint technical committee, which is known as ISO/IEC JTC 1.

Harmonization

In recent years, national, regional, and international standards-making bodies have joined efforts to harmonize the standards affecting ICT. These efforts, along with the technological developments that impact standards, codes, and regulations, maintain the dynamic nature of the documents.

Continuous standards harmonization efforts do not guarantee that all of the unique requirements for a specific design work area are covered. Since other disciplines (e.g., data processing, telephony, construction, architecture) are involved in the telecommunications design, the designer should also be knowledgeable about these related codes, standards, and local and national regulations.

Independent Standards-Setting Organizations

A number of independent organizations specialize in establishing, certifying, and maintaining standards. Many industry trade organizations and national and international standards-setting bodies develop standards. Some of these organizations are listed in Appendix A: Codes, Standards, Regulations, and Organizations.

