# 6. CABLE TYPES AND SELECTION CRITERIA

## 6.1 PORTABLE POWER AND CONTROL

### 6.1.1 Flexible Cords

Flexible cords come in a number of UL and CSA types including SO, SOW, SOOW, SJ, SJO, SJOW, STO and SJTO. In portable cord terminology, each letter of the cable type indicates the construction of the cable. For example: S = service, O = oil-resistant jacket, J = junior service (300 volts), W = weather resistant, T = thermoplastic, and OO = oil-resistant insulation and jacket.

The temperature rating of these cables can range from -50°C to +105°C for SOOW and -37°C to +90°C for other thermoset cords. Thermoplastic cords typically have temperature ratings that range from -20°C to +60°C. Thermoset portable cords have excellent cold bend characteristics and are extremely durable.

**Table 6.1–Flexible Cord Type Designations**

| | |
|---|---|
| TST | Tinsel Service Thermoplastic |
| SPT-1 | Service Parallel Thermoplastic – 1/64" Insulation |
| SPT-2 | Service Parallel Thermoplastic – 2/64" Insulation |
| SPT-3 | Service Parallel Thermoplastic – 3/64" Insulation |
| SPE-1 | Service Parallel Elastomer – 1/64" Insulation |
| SPE-2 | Service Parallel Elastomer – 2/64" Insulation |
| SPE-3 | Service Parallel Elastomer – 3/64" Insulation |
| SV | Service Vacuum |
| SVO | Service Vacuum Oil-Resistant Jacket |
| SVOO | SVO with Oil-Resistant Insulation |
| SVT | Service Vacuum Thermoplastic |
| SVTO | SVT with Oil-Resistant Jacket |
| SVTOO | SVTO with Oil-Resistant Insulation |
| SVE | Service Vacuum Elastomer |
| SVEO | SVE with Oil-Resistant Jacket |
| SVEOO | SVEO with Oil-Resistant Insulation |
| SJ | Service Junior |
| SJO | SJ with Oil-Resistant Jacket |
| SJOO | SJO with Oil-Resistant Insulation |
| SJOOW | Weather Resistant SJOO |
| SJT | Service Junior Thermoplastic |
| SJTO | SJT with Oil-Resistant Jacket |
| SJTOO | SJTO with Oil-Resistant Insulation |
| SJTOOW | Weather-Resistant SJTOO |
| SJE | Service Junior Elastomer |
| SJEO | SJE with Oil-Resistant Jacket |
| SJEOO | SJEO with Oil-Resistant Insulation |
| SJEOOW | Weather Resistant SJEOO |
| S | Service |
| SO | Service with Oil-Resistant Jacket |

Continued on next page >>

**Table 6.1—Flexible Cord Type Designations (Continued)**

| | |
|---|---|
| SOO | SO with Oil-Resistant Insulation |
| SOOW | Weather-Resistant SOO |
| ST | Service Thermoplastic |
| STO | ST with Oil-Resistant Jacket |
| STOO | STO with Oil-Resistant Insulation |
| STOOW | Weather-Resistant STOO |
| SE | Service Elastomer |
| SEO | SE with Oil-Resistant Jacket |
| SEOO | SEO with Oil-Resistant Insulation |
| SEOOW | Weather-Resistant SEOO |
| HPN | Heater Parallel Neoprene |
| HSJ | Heater Service Junior |
| HSJO | HSJ with Oil-Resistant Jacket |

### 6.1.2 Mining Cable

Mine power cables are generally designed to be used as flexible feeder cables for circuits between the main power source and mine load centers or as equipment trailing cables.

Mine power feeder (MPF) cables typically have voltage ratings of 5, 8, 15 or 25 kV and are available with or without a ground check conductor. A ground check (GC) conductor is a separate insulated ground wire that is used to monitor the "health" of the normal ground wire. MPF cables are flexible but are designed for only limited or occasional movement.

Shovel (SHD) cables are generally used to power heavy duty mobile mining equipment. SHD cables are unique in that they not only carry voltage ratings up to 25 kV but also have great flexibility and incredible physical toughness. Like mine power cables, SHD cables are generally available with or without a ground check conductor.

For low-voltage applications, there are a number of portable cables used by the mining industry. Among the most common are Type W and Type G. Both cables are a heavy-duty construction, can withstand frequent flexing and carry a voltage rating of up to 2 kV.

## 6.2 CONSTRUCTION AND BUILDING WIRE

Construction and building wire encompasses a wide variety of 300- and 600-volt wire and cable including UL Types THW, THW-2, THWN, THWN-2, THHN, TFFN, TFN, RHH, RHW, RHW-2, USE, USE-2, thermostat wire, SER, SE-U, XHHW, XHHW-2 and others. This category of wire is typically used as the permanent wiring in residential, commercial and industrial facilities. UL types with a "-2" suffix are rated 90°C in both dry and wet locations. In building wire terminology, each letter of the wire type indicates something about the construction. For example:

THHN – Thermoplastic, High Heat resistant, Nylon jacket

THWN-2 – Thermoplastic, Heat resistant, Wet and dry locations (-2 means 90°C wet), Nylon jacket

XHHW-2 – Cross-linked (X) insulation, High Heat resistant, Wet and dry locations (-2 means 90°C wet)

RHHW-2 – Rubber insulation, High Heat resistant, Wet and dry locations (-2 means 90°C wet)

USE-2 – Underground Service Entrance wire (-2 means 90°C wet)

## 6.3 CONTROL, INSTRUMENTATION AND THERMOCOUPLE

### 6.3.1 Control Cable

Control cables differ from power cables in that they are used to carry intermittent control signals, which generally require little power. Therefore, current loading is rarely a deciding factor in the choice of control cable. Primary criteria that are applied to the selection of control cable are voltage level and environmental conditions. The voltage level for control circuits may range anywhere from millivolts up to several hundred volts.

#### Environmental Conditions

Control cables are generally subject to rather severe environmental conditions. For this reason an examination of these conditions is at least as important as electrical considerations. High ambient temperature conditions (such as near boilers and steam lines), along with possible exposure to oils, solvents and other chemicals (in chemical, petroleum, steel, pulp and paper and cement plants), are vital considerations.

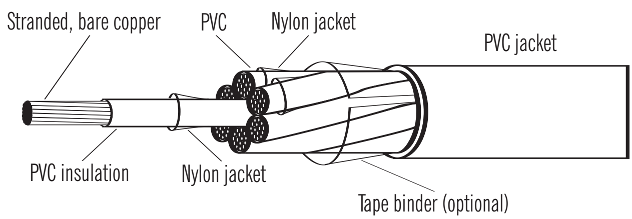



Figure 6.1–A Typical 600 V Control Cable

### 6.3.2 Instrumentation Cable

Instrumentation cable is generally used to transmit a low-power signal from a transducer (measuring for example, pressure, temperature, voltage, flow, etc.) to a PLC or DCS process control computer or to a manually operated control panel. It is normally available in 300- or 600-volt constructions with a single overall shield, or with individual shields over each pair (or triad) and an overall shield.

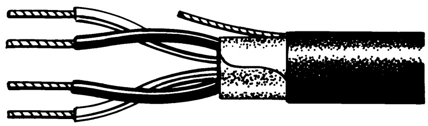


Figure 6.2–Control Cable with Overall Shield

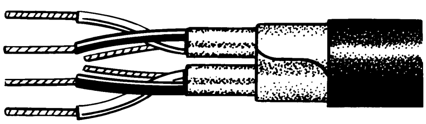


Figure 6.3–Control Cable with Individually Shielded Pairs and An Overall Shield

### 6.3.3 Thermocouple Wire

A thermocouple is a temperature measuring device consisting of two conductors of dissimilar metals or alloys that are connected together at one end. At this thermocouple junction, as it is called, a small voltage is produced. Electronic equipment senses this voltage and converts it to temperature. Thermocouple wire is available in either thermocouple grade or extension grade. Extension grade wire is normally lower in cost and is recommended for use in connecting thermocouples to the sensing or control equipment. The conditions of measurement determine the type of thermocouple wire and insulation to be used. Temperature range, environment, insulation requirements, response and service life should be considered. Note that thermocouple wire color codes can vary around the world.

**Thermocouple Types**

Type J (Iron vs Constantan) is used in vacuum, oxidizing, inert or reducing atmospheres. Iron oxidizes rapidly at temperatures exceeding 538°C (1,000°F), and therefore heavier gauge wire is recommended for longer life at these temperatures.

Type K (Chromel vs Alumel) is used in oxidizing, inert or dry reducing atmospheres. Exposure to a vacuum should be limited to short time periods. Must be protected from sulfurous and marginally oxidizing atmospheres. Reliable and accurate at high temperatures.

Type T (Copper vs Constantan) is used for service in oxidizing, inert or reducing atmospheres or in a vacuum. It is highly resistant to corrosion from atmospheric moisture and condensation and exhibits high stability at low temperatures; it is the only type with limits of error guaranteed for cryogenic temperatures.

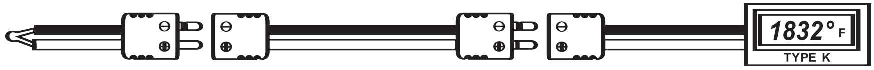
Type E (Chromel vs Constantan) may be used in oxidizing, inert or dry reducing atmospheres, or for short periods of time under vacuum. Must be protected from sulfurous and marginally oxidizing atmospheres. Produces the highest EMF per degree of any standardized thermocouple.

Type R and S (Platinum vs Rhodium) are used in oxidizing or inert atmospheres. Must be protected from contamination. Reliable and accurate at high temperatures.

Thermocouple wire can be fabricated into an accurate and dependable thermocouple by joining the thermoelements at the sensing end.

Thermocouple wire or thermocouple extension wire of the same type must be used to extend thermocouples to indicating or control instrumentation. Red color code is negative throughout circuit.

Hook up red color-coded wire to negative terminal of instrument.




Temperature limit of the thermocouple depends on the thermocouple wire: wire size; wire insulation; and environmental factors.

Use thermocouple connectors if required. They are made of the same alloys and have the same color codes as extension wire.

Source: PMC Corporation

Figure 6.4–A Typical Thermocouple Circuit

### Table 6.2–Color Code for Thermocouple Wire Per ANSI/ISA MC96.1

| Thermocouple Type | | Color Code | |
|---|---|---|---|
| Wire Alloys | ANSI Symbol | +/– Individual | Jacket |
| *Iron (+) vs Constantan (–) | J | White/Red | Brown |
| Chromel (+) vs *Alumel (–) | K | Yellow/Red | Brown |
| Copper (+) vs Constantan (–) | T | Blue/Red | Brown |
| Chromel (+) vs Constantan (–) | E | Purple/Red | Brown |
| Platinum (+) vs 13% Rhodium (–) | R | – | – |
| Platinum (+) vs 10% Rhodium (–) | S | – | – |

*Magnetic

### Table 6.3–Color Code for Thermocouple Extension Wire Per ANSI/ISA MC96.1

| Thermocouple Type | | Color Code | |
|---|---|---|---|
| Wire Alloys | ANSI Symbol | +/– Individual | Jacket |
| *Iron vs Constantan | JX | White/Red | Black |
| Chromel vs *Alumel | KX | Yellow/Red | Yellow |
| Copper vs Constantan | TX | Blue/Red | Blue |
| Chromel vs Constantan | EX | Purple/Red | Purple |
| Platinum vs 13% Rhodium (–) | RX | Black/Red | Green |
| Platinum vs 10% Rhodium (–) | SX | Black/Red | Green |

*Magnetic

## 6.4 HIGH TEMPERATURE

High temperature generally refers to wire or cable with a temperature rating of 125°C (257°F) or higher. The table below lists some of the most common high-temperature wire and cable types along with their temperature rating.

### Table 6.4–High-temperature Wire and Cable

| °C | °F | Type |
|---|---|---|
| 538 | 1,000 | MG (Non-UL) |
| 450 | 842 | MG (UL Style 5107) |
| 250 | 482 | TGGT (UL Styles 5196 and 5214), TKGT (UL Style 5214) TMMG, TCGT (UL Style 5288) |
| 200 | 392 | SRG (UL Styles 3071, 3074, 3075, 3125, 3172 and 3231), SRK, SRGK and UL Types SF-2 and SFF-2 |
| 150 | 302 | SRG, TGS and UL Styles 3212, 3213 and 3214 |
| 125 | 257 | UL Style 3284 and CSA CL1254 |

## 6.5 POWER

Below are some of the key considerations when selecting a power cable:

- System voltage
- Current loading (ampacity)
- External thermal conditions such as ambient temperature, proximity of other cables, adjacent sources of heat, thermal conductivity of soil, etc.
- Voltage drop
- Special conditions, such as the presence of corrosive agents, flexibility and flame resistance

### 6.5.1 Voltage Rating

The system voltage on which the cable is to operate determines the required cable voltage rating. Cables rated 5 kV and above are separated into two classifications: grounded systems (100 percent insulation level) and ungrounded systems (133 percent insulation level). In case of a phase-to-ground fault in a three-phase system, it is possible to operate ungrounded systems for up to one hour with one conductor at ground potential. This condition results in full line-to-line voltage stress across the insulation of each of the other two conductors. For this reason each conductor of such a circuit must have additional insulation. Cables designed for use on grounded systems take advantage of the absence of this full line-to-line voltage stress across the insulation and use thinner insulation. The direct result of such a design is lower cost, as well as reduced cable diameter.

A recent change in the NEC now requires all cables operating above 2,400 volts in the U.S. to be shielded.

### 6.5.2 Conductor Size

Conductor size is based principally on three considerations:

- Current-carrying capacity (ampacity)
- Short-circuit current
- Voltage drop

The current-carrying capacity of a cable is affected primarily by the permissible operating temperature of its insulation. The higher the operating temperature of the insulation, the higher the current-carrying capacity of a given conductor size. The temperature at which a particular cable will operate is affected by the ability of the surrounding material to conduct away the heat. Therefore, the current-carrying capacity is materially affected by the ambient temperature as well as by the installation conditions. For example, a cable installed in a 40°C ambient temperature has an ampacity that is only about 90 percent of the ampacity in a 30°C ambient.

Running a single-conductor cable through a magnetic conduit will increase the apparent resistance of the cable and will also result in a lower current-carrying capacity due to the additional resistance and magnetic losses. Similarly, when a cable is run close to other cables, the presence of the other cables effectively increases the ambient temperature, which decreases the ability of the cable to dissipate its heat. It is apparent from the above that many conditions must be known before an accurate current-carrying capacity can be determined for a particular cable installation.

Occasionally, emergency overload conditions are also involved and may affect conductor size.

### 6.5.3 Short Circuit Current

A second consideration in selection of conductor size is that of the short circuit current, which the cable must be able to carry in an emergency. From a thermal standpoint there is a limit to the amount of short-circuit current that a cable can handle without damage.

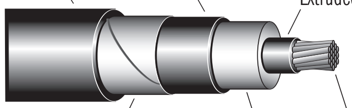



Figure 6.5–Typical Tape Shielded 15 kV Power Cable

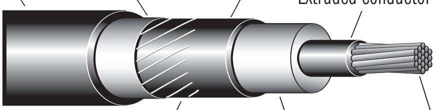



Figure 6.6–Typical Wire Shielded 15 kV Power Cable

### 6.5.4 Voltage Drop Considerations

Cable conductor size is sometimes governed by voltage drop rather than by heating. Generally, conductor size on long, low-voltage lines is governed by voltage drop; on short, high-voltage lines by heating. Due to voltage drop considerations, it might be necessary to increase conductor size, even though the current load is adequately handled by a smaller size conductor.

### 6.5.5 Special Conditions

The following are only a few of the many special conditions that may affect cable selection:

- The presence of large sources of heat (boilers, steam lines, etc.)
- The effect of magnetic materials such as pipes or structural members close to large cables carrying heavy current loads
- The presence of corrosive chemicals in the soil or other locations in which the cable is installed
- The interference that may occur in telecommunication circuits because of adjacent power cables
- Flame and radiation resistance
- Mechanical toughness
- Moisture resistance
- Overload and fault current requirements

All special conditions should be carefully investigated, and the advice of competent engineers obtained, before proceeding with an important cable installation.

## 6.6 ARMORED POWER AND CONTROL

Armored cables comprise a group of cables that are designed to withstand severe mechanical and chemical environments. For information on the various types and their applications, see **Section 5** on armor.

## 6.7 ELECTRONIC CABLE

This category of wire and cable covers thousands of small gauge single-conductor wire types along with many types of multiconductor cables. These basic types come in various combinations of stranding, insulation material, conductor count, jacket material, etc. Some common types and key characteristics are described below.

### 6.7.1 Coaxial Cable

A coaxial cable consists of four basic parts:

- Inner conductor (center conductor)
- Outer conductor (shield)
- Dielectric, which separates the inner and outer conductors
- Jacket, which is the outer polymer layer protecting the parts inside

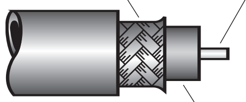



**Figure 6.7–Typical Coaxial Cable**

**Characteristic Impedance**

The characteristic impedance of a coaxial cable is a function of its geometry and materials. Characteristic impedance is independent of length and typically ranges from 35 to 185 ohms. The most common values are 50, 75 and 93 ohms. The characteristic impedance of a cable should not be confused with the impedance of the conductors in a cable, which is dependent on length.

The most efficient transfer of energy from a source to a load occurs when all parts of the system have the same characteristic impedance. For example, a transmitter, interconnecting cable and receiver should all have the same impedance. This need for impedance matching is especially critical at higher frequencies, where the consequences of mismatches are more severe.

**VSWR**

The Voltage Standing-Wave Ratio (VSWR) is a measure of the standing waves that result from reflections. It expresses the uniformity or quality of a cable’s characteristic impedance. Uniformity is also measured as structural return loss (SRL).

**Velocity of Propagation**

Velocity of propagation is the speed at which electromagnetic energy travels along the cable. In free space or air, electromagnetic energy travels at the speed of light, which is 186,000 miles per second. In other materials, however, the energy travels slower, depending on the dielectric constant of the material. Velocity of propagation is expressed as a percentage of the speed of light. For example, a velocity of 65 percent means that the energy travels at 120,900 miles per second – or 35 percent slower than in free space.

The dielectric (insulation) separating the two conductors determines the velocity of propagation. Although the electromagnetic energy travels in the dielectric, the current associated with the energy travels primarily on the outside of the center conductor and the inside of the outer conductor (shield). The two conductors bind the energy within the cable. Consequently, the quality of the dielectric is important to efficient, speedy transfer of energy. Speed is important to engineers who must know the transit time of signals for digital transmission.

### Voltage Rating
This is the maximum voltage the cable is designed to handle.

### Operating Temperature Range
This is the minimum and maximum temperatures at which the cable can operate.

### Coaxial Types
The following paragraphs describe four common types of coaxial cable.

- **Flexible Coax**
  The most common type, flexible coax has a braided outer conductor (shield) of extremely fine wires. While the braid makes the cable flexible, it does not provide complete shielding – energy (RF signals) can leak through the shield via minute gaps in the braid. To combat this, many cables have several layers in the outer conductor. In addition, thin foils are sometimes used to supplement the braid to provide better coverage for greater shielding effectiveness. The greater the coverage, the better the shield.
- **Semirigid Coax**
  Semirigid coax has a solid, tubular metallic outer conductor, similar to a pipe. This construction gives the cable a very uniform characteristic impedance (low VSWR) and excellent shielding, but at the expense of flexibility.
- **Triaxial Cable (Triax)**
  This coax has two outer conductors (shields) separated by a dielectric layer. One outer conductor (shield) serves as a signal ground, while the other serves as earth ground, providing better noise immunity and shielding. One caution: Do not confuse a flexible cable having a multilayer outer shield with triaxial cable.
- **Dual Coax**
  This cable contains two individual coaxial cables surrounded by a common outer jacket.

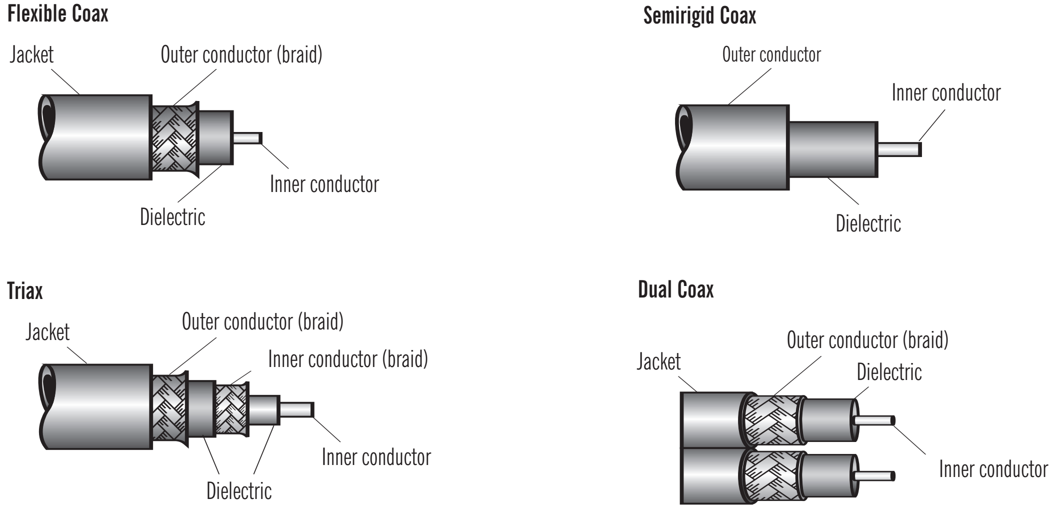
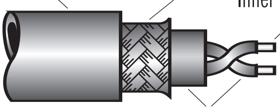



**Figure 6.8–Common Types of Coaxial Cable**

### 6.7.2 Twinaxial Cable (Twinax)

Twinax has a pair of insulated conductors encased in a common outer conductor (shield). The center conductors may be either twisted or run parallel to one another. In appearance, the cable is often similar to a shielded twisted pair, but it is held to the tighter tolerances common to fixed-impedance coaxial cable. A common use of twinax is high-speed, balanced-mode multiplexed transmission in large computer systems. Balanced mode means that the signal is carried on both conductors, which provides greater noise immunity.




Figures 6.9–A Typical Twinaxial Cable

### 6.7.3 100 ohm Twisted Pair Cable

100 ohm unshielded twisted pair (UTP) and shielded twisted pair are low pair count cables (usually 4 pairs) that have been designed for use in local area networks such as Ethernet. Because of their relatively low cost these cable types are widely used and are available in several different performance categories (levels) – currently Categories 3, 5e, 6 and 6A. Insertion loss, crosstalk, impedance and other electrical parameters are specified in TIA/EIA-568-B.2 and its related addenda. A summary of their electrical requirements are shown below.

**Table 6.5–Category 3 Performance (100 meters)**

| Frequency (MHz) | Insertion Loss (dB) | NEXT (dB) | PSNEXT (dB) |
|---|---|---|---|
| 0.772 | 2.2 | 43.0 | 43 |
| 1.0 | 2.6 | 40.3 | 41 |
| 4.0 | 5.6 | 32.3 | 32 |
| 8.0 | 8.5 | 27.8 | 28 |
| 10.0 | 9.7 | 26.3 | 26 |
| 16.0 | 13.1 | 23.2 | 23 |

Maximum propagation delay: 545 ns/100 m at 10 MHz
Maximum delay skew: 45 ns/100 m at 16 MHz
Characteristic impedance: 100±15 ohms from 1 to 16 MHz

**Table 6.6–Category 5e Performance (100 meters)**

| Frequency (MHz) | Insertion Loss (dB) | NEXT (dB) | PSNEXT (dB) | ELFEXT (dB) | PSELFEXT (dB) | Return Loss (dB) |
|---|---|---|---|---|---|---|
| 0.772 | 1.8 | 67.0 | 64.0 | – | – | 19.4 |
| 1.0 | 2.0 | 65.3 | 62.3 | 63.8 | 60.8 | 20.0 |
| 4.0 | 4.1 | 56.3 | 53.3 | 51.8 | 48.8 | 23.0 |
| 8.0 | 5.8 | 51.8 | 48.8 | 45.7 | 42.7 | 24.5 |
| 10.0 | 6.5 | 50.3 | 47.3 | 43.8 | 40.8 | 25.0 |
| 16.0 | 8.2 | 47.2 | 44.2 | 39.7 | 36.7 | 25.0 |
| 20.0 | 9.3 | 45.8 | 42.8 | 37.8 | 34.8 | 25.0 |
| 25.0 | 10.4 | 44.3 | 41.3 | 35.8 | 32.8 | 24.3 |
| 31.25 | 11.7 | 42.9 | 39.9 | 33.9 | 30.9 | 23.6 |
| 62.5 | 17.0 | 38.4 | 35.4 | 27.9 | 24.9 | 21.5 |
| 100.0 | 22.0 | 35.3 | 32.3 | 23.8 | 20.8 | 20.1 |

Maximum propagation delay: 538 ns/100 m at 100 MHz
Maximum delay skew: 45 ns/100 m at 100 MHz

**Table 6.7–Category 6 Performance (100 meters)**

| Frequency (MHz) | Insertion Loss (dB) | NEXT (dB) | PSNEXT (dB) | ELFEXT (dB) | PSELFEXT (dB) | Return Loss (dB) |
|---|---|---|---|---|---|---|
| 0.772 | 1.8 | 76.0 | 74.0 | 70.0 | 67.0 | 19.4 |
| 1.0 | 2.0 | 74.3 | 72.3 | 67.8 | 64.8 | 20.0 |
| 4.0 | 3.8 | 65.3 | 63.3 | 55.8 | 52.8 | 23.0 |
| 8.0 | 5.3 | 60.8 | 58.8 | 49.7 | 46.7 | 24.5 |
| 10.0 | 6.0 | 59.3 | 57.3 | 47.8 | 44.8 | 25.0 |
| 16.0 | 7.6 | 56.2 | 54.2 | 43.7 | 40.7 | 25.0 |
| 20.0 | 8.5 | 54.8 | 52.8 | 41.8 | 38.8 | 25.0 |
| 25.0 | 9.5 | 53.3 | 51.3 | 39.8 | 36.8 | 24.3 |
| 31.25 | 10.7 | 51.9 | 49.9 | 37.9 | 34.9 | 23.6 |
| 62.5 | 15.4 | 47.4 | 45.4 | 31.9 | 28.9 | 21.5 |
| 100.0 | 19.8 | 44.3 | 42.3 | 27.6 | 24.8 | 20.1 |
| 200.0 | 29.0 | 39.8 | 37.8 | 21.8 | 18.8 | 18.0 |
| 250.0 | 32.8 | 38.3 | 36.3 | 19.8 | 16.8 | 17.3 |

Maximum propagation delay: 538 ns/100 m at 100 MHz (536 at 250 MHz)
Maximum delay skew: 45 ns/100 m at all frequencies

**Table 6.8–Category 6A Performance (100 meters)**

| Frequency (MHz) | Insertion Loss (dB) | NEXT (dB) | PSNEXT (dB) | ACRF (dB) | PSACRF (dB) | Return Loss (dB) | PSANEXT (dB) | PSAACRF (dB) |
|---|---|---|---|---|---|---|---|---|
| 1.0 | 2.1 | 74.3 | 72.3 | 67.8 | 64.8 | 20.0 | 67.0 | 67.0 |
| 4.0 | 3.8 | 65.3 | 63.3 | 55.8 | 52.8 | 23.0 | 67.0 | 66.2 |
| 8.0 | 5.2 | 60.8 | 58.8 | 49.7 | 46.7 | 24.5 | 67.0 | 60.1 |
| 10.0 | 5.9 | 59.3 | 57.3 | 47.8 | 44.8 | 25.0 | 67.0 | 58.2 |
| 16.0 | 7.5 | 56.2 | 54.2 | 43.7 | 40.7 | 25.0 | 67.0 | 54.1 |
| 20.0 | 8.4 | 54.8 | 52.8 | 41.8 | 38.8 | 25.0 | 67.0 | 52.2 |
| 25.0 | 9.4 | 53.3 | 51.3 | 39.8 | 36.8 | 24.3 | 67.0 | 50.2 |
| 31.25 | 10.5 | 51.9 | 49.9 | 37.9 | 34.9 | 23.6 | 67.0 | 48.3 |
| 62.5 | 15.0 | 47.4 | 45.4 | 31.9 | 28.9 | 21.5 | 67.0 | 42.3 |
| 100.0 | 19.1 | 44.3 | 42.3 | 27.8 | 24.8 | 20.1 | 67.0 | 38.2 |
| 150.0 | 23.7 | 41.7 | 39.7 | 24.3 | 21.3 | 18.9 | 67.0 | 34.7 |
| 200.0 | 27.6 | 39.8 | 37.8 | 21.8 | 18.8 | 18.0 | 64.5 | 32.2 |
| 250.0 | 31.1 | 38.3 | 36.3 | 19.8 | 16.8 | 17.3 | 62.5 | 30.2 |
| 300.0 | 34.3 | 37.1 | 35.1 | 18.3 | 15.3 | 16.8 | 61.0 | 28.7 |
| 350.0 | 37.2 | 36.1 | 34.1 | 16.9 | 13.9 | 16.3 | 59.6 | 27.3 |
| 400.0 | 40.1 | 35.3 | 33.3 | 15.8 | 12.8 | 15.9 | 58.5 | 26.2 |
| 450.0 | 42.7 | 34.5 | 32.5 | 14.7 | 11.7 | 15.5 | 57.4 | 25.1 |
| 500.0 | 45.3 | 33.8 | 31.8 | 13.8 | 10.8 | 15.2 | 56.5 | 24.2 |

Maximum propagation delay: 538 ns/100 m at 100 MHz
Maximum delay skew: 45 ns/100 m at all frequencies

**100-ohm Unshielded Twisted Pair (UTP) vs Shielded Twisted Pair**

There are two basic types of electromagnetic interference (EMI) that cable engineers worry about – EMI emissions and EMI immunity. Emissions refer to energy that is radiated by the cable that might affect the proper operation of a neighboring circuit or system. Immunity is the ability of the cable to reject outside signals that might interfere with the proper operation of the circuit or system to which the cable is attached.

Electromagnetic interference is present in all types of cabling to some degree. In local area networks (LANs), failure to properly manage EMI can have an adverse effect on the integrity of the transmitted information.

Shielded cables generally use an aluminum or copper shield to provide protection. When properly grounded (connected) to the associated electronic equipment, the shield acts as a barrier to incoming as well as outgoing EMI.

In an unshielded (UTP) cable, careful design of the cable and the associated electronic equipment results in a "balance" of the currents in the two conductors of a pair. That is, the currents in the two conductors are equal in magnitude but flowing in opposite directions. In a balanced system, there is very little radiation of EMI since the external field from one conductor is effectively canceled by the external field from the other conductor of the pair.

Generally, the more twists per foot in the conductor pairs of the cable, the better the cable is electrically balanced. For example, Category 5e cable has more twists per foot than Category 3 cable and, therefore, offers better protection from EMI problems.

## 6.7.4 IBM Cabling System

The IBM Cabling System is a structured building wiring system that is compatible with IEEE 802.5 (Token Ring) networks and equipment. Cable types consist of various combinations of shielded data grade media (DGM) and non-shielded voice grade media (VGM). Cable types include "Type 1," which is a 2-pair DGM cable, "Type 2," which contains two DGM pairs plus four VGM pairs and "Type 6," which is a 2-pair DGM cable with smaller conductors (26 AWG instead of 22 AWG).

## 6.8 TELEPHONE

Telephone cables play a major role in modern communications. In conjunction with microwave and satellite transmission, copper and optical fiber cables provide the communication links that have become essential to society.

With the advent of optical fiber cables in the early 1980s, telephone wire and cable has generally been grouped into three broad categories: 1) fiber, 2) copper and 3) hybrid (composite) cable with both fiber and copper components under one jacket.

Telephone cable is usually classified according to its location of use. Cable used outdoors between the telephone company's central office and the building being served is referred to as outside cable, or sometimes called black cable. Wire or cable used indoors, e.g., inside homes and commercial buildings, is referred to as premises distribution wiring or more simply as inside cable.

### 6.8.1 Outside Cables

Outside cables typically range in size from small (2 to 6 pair) constructions, which are usually referred to as "service drop" or "buried distribution" wire (the cable installed in many residential backyards), up to large 1,500 pair "exchange" cables, which are typically installed between central offices of the telephone company. Many high pair-count copper cables have been replaced by optical fiber cables.

Exchange cables, because they are often installed in underground ducts or directly buried in the earth, are designed with various combinations of polyethylene (PE) jackets and aluminum, copper or steel sheaths. The PE jacket and metal armoring isolate signal-carrying conductor pairs from moisture, mechanical damage and lightning induced voltages.

Exchange cables are manufactured in "filled" and "unfilled" (aircore) versions. With filled cables, the interstices between insulated conductors are filled with a waterproofing gel to prevent the ingress and longitudinal movement of water. Some aircore cable designs are kept dry by pressurizing the core of the cable with dry air or nitrogen. Water is the "Achilles' heel" of outdoor telephone cable because it increases capacitance (normally 0.083 $\mu$F per mile) between the "tip" and "ring" conductors and compromises crosstalk (pair-to-pair signal coupling) performance of the cable.

The terms tip and ring are carryovers from earlier days when each twisted pair was terminated with a 1/4-inch diameter plug at a manually operated switchboard. One conductor was attached to the tip, the other to the ring of the plug.

### 6.8.2 Indoor Cables

Inside wire and cable is usually divided into 1) station wire and 2) inside cable (sometimes called IC). Station wire is usually 2 to 4 pair, 22 or 24 AWG wire and is typically installed in residences.

While station wire is one type of inside wire, it is usually designed for both indoor and outdoor use because it often extends to the exterior of the building. True inside cable, on the other hand, is typically larger (25 to 200 pair) 22 or 24 AWG cable, which is installed exclusively indoors in larger public and commercial buildings. Station wire and inside cables are usually used in plenum, riser, and general purpose versions. The plenum version is a highly flame retardant construction that is capable of passing the Steiner Tunnel Flame Test (NFPA-262).

Article 800 of the National Electrical Code (NEC) requires that telephone wire and cable be plenum rated when installed indoors in plenums (air handling spaces) without conduit, i.e., it must carry the marking CMP (CM for communication and P for plenum). When installed in vertical risers in multistory buildings, a riser rating, i.e., Type CMR, is required. General purpose communication cables must be labeled Type CM. Cables installed in one- and two-family dwellings must be identified as Type CMX.

### 6.8.3 Insulation and Jacket Materials

Two thermoplastic polymers are generally used to insulate the conductors of outdoor telephone wire and cable: polypropylene (PP) or polyethylene (PE). These polymers are used primarily because of their low dielectric constant, high dielectric strength (to withstand lightning induced overvoltages), excellent moisture resistance, mechanical toughness, extrudability in thin walls and low cost. Indoor dielectrics include PP and PE but, in addition, include FEP (fluorinated ethylene-propylene or Teflon), ECTFE (ethylene-chlorotrifluoroethylene or Halar) and PVC (polyvinyl chloride). FEP and ECTFE are used in plenum cables to provide the necessary flame retardancy and are extruded on the wire in either solid or foamed (expanded) versions.

The most important telephone wire and cable electrical characteristics and their usual units of measurement include capacitance (microfarads per mile), conductor resistance (ohm per loop-mile), crosstalk (decibel isolation between pairs) and attenuation (decibels per mile). When used for high-speed digital applications, characteristic impedance (ohm) and structural return loss (decibels) also become important.

The mechanical and chemical characteristics of telephone cable insulation are as important as the electrical characteristics. Several important mechanical and chemical characteristics include compression cut resistance, low-temperature brittleness, resistance to the base oils used in filling gels, adequate tensile and elongation properties, and acceptable long-term aging characteristics.

## 6.9 MILITARY

The U.S. military has developed extensive specifications for many wire and cable types used in military applications. This includes hook-up and lead wire, airframe wire, control cable and coax. A MIL-Spec wire or cable must meet rigorous performance requirements. Tests that prove the wire or cable meets the specified requirements must be conducted by the manufacturer and must be carefully documented.

Following is a partial list of military wire and cable types.

| Type | Description |
|---|---|
| MIL-C-5756 | Cable and wire, portable power, rubber insulated (replaced by SAE-AS5756) |
| MIL-C-7078 | Cable, aerospace vehicle (replaced by NEMA WC27500) |
| MIL-C-13294 | Field wire (replaced by MIL-DTL-49104) |
| MIL-DTL-915 | Shipboard cable (inactive for new design except outboard types) |
| MIL-DTL-3432 | Power and special purpose cables used for ground support systems (“CO” types), 300 and 600 V |
| MIL-DTL-8777 | Aircraft wire, silicone insulated, 600 V, 200°C |
| MIL-DTL-13486 | Cable, special purpose, low tension, single and multiconductor, shielded and unshielded |
| MIL-DTL-16878 | General purpose hook-up and lead wire |
| MIL-DTL-24640 | Shipboard cable, lightweight |
| MIL-DTL-24643 | Shipboard cable, low smoke |
| MIL-DTL-25038 | Aircraft wire, inorganic fibrous/Teflon insulation, high temperature and fire resistant, engine zone wire |
| MIL-DTL-23053 | Tubing, heat shrink (replaced by AMS-DTL-23053) |
| MIL-DTL-27072 | Cable, power and special purpose, multiconductor and single shielded (replaced by NEMA WC27500) |
| MIL-DTL-27500 | Aerospace and other general application wire |

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**(Continued)**

| Type | Description |
|---|---|
| MIL-DTL-49055 | Cable, power, flat, unshielded |
| MIL-DTL-55021 | Cable, shielded singles, twisted pairs and triples, internal hook-up |
| MIL-I-22129 | Tubing, PTFE, nonshrink |
| MIL-W-76 | General purpose hook-up wire |
| MIL-W-5845 | Thermocouple wire, iron and Constantan |
| MIL-W-5846 | Thermocouple wire, chromel and alumel |
| MIL-W-81822 | Solderless wrap (wire wrap), insulated and uninsulated |
| MIL-W-47206 | Cable, single conductor, twisted pairs; and multiconductor, high temperature (replaced by MIL-DTL-27500) |

## 6.10 SHIPBOARD CABLES (MIL-DTL-24643, MIL-DTL-24640 AND MIL-DTL-915)

Due to concern about flammability, smoke and toxicity, the U.S. Navy introduced the MIL-DTL-24643 cable specification. Generally, this document provides low-smoke, fire-retardant cables that are approximately equivalent in size, weight and electricals to many of the older MIL-DTL-915 constructions.

In consideration of circuit density, weight and size, the U.S. Navy produced the MIL-DTL-24640 cable document. The cables covered by this specification are also low-smoke, fire-retardant constructions, but they are significantly lighter in weight and smaller in diameter. MIL-DTL-24640 cables are used to interconnect systems where weight and space savings are critical; however, they are not direct replacements. Because the overall diameters have been reduced and electrical characteristics may have been changed, they should not be used to replace existing MIL-DTL-915 or MIL-DTL-24643 constructions unless a comprehensive electrical and physical system evaluation or redesign has been completed.

For many years, most of the shipboard power and lighting cables for fixed installation had silicone-glass insulation, polyvinyl chloride jacket, and aluminum armor and were of watertight construction. It was determined that cables with all of these features were not necessary for many applications, especially for applications within watertight compartments and noncritical areas above the watertightness level. Therefore, for applications within watertight compartments and noncritical areas, a new family of non-watertight lower cost cables was designed. This family of cables is electrically and dimensionally interchangeable with silicone-glass insulated cables of equivalent sizes and is covered by Military Specification MIL-DTL-915.

## 6.11 OPTICAL FIBER CABLES

In all types of optical fiber cables, the individual optical fibers are the signal transmission media that act as individual optical wave guides. The fibers consist of a central transparent core region that propagates the optical radiation and an outer cladding layer that completes the guiding structure. The core and the cladding are typically made of pure silica glass, though other materials can be used. To achieve high signal bandwidth capabilities, the core region sometimes has a varying (or graded) refractive index.

## 6.11.1 Fiber Types

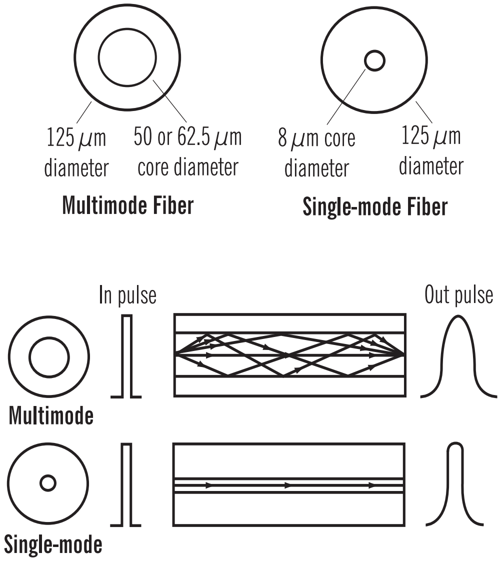


Figure 6.10–Optical Fiber Types

There are two basic fiber types – single-mode and multimode. Single-mode has a core diameter of 8 to 10 microns and is normally used for long distance requirements (e.g., interstate) and high-bandwidth (information carrying capacity) applications. Multimode, on the other hand, has a core diameter of 50 or 62.5 microns and is usually used intrabuilding.

Laser-optimized fibers are a fairly recent development in which 50-micron multimode fibers are optimized for 850 nm VCSEL (vertical cavity surface emitting laser) sources and can provide significantly increased bandwidth performance when compared with standard multimode fiber types. The added bandwidth of laser-optimized 50-micron fiber allows for distance support up to 550 meters for 10 Gigabit Ethernet networks as well as providing a lower overall system cost when compared with single-mode systems utilizing higher cost 1300 or 1550 laser sources. Laser-optimized fiber is referred to as "OM3" fiber in ISO/IEC-11801. OM3 fibers are also referenced by other industry standards, such as the TIA-568 wiring standards and Institute of Electrical and Electronics Engineers (IEEE). OM1 and OM2 designations are specified for standard 62.5 and 50 micron multimode fibers, respectively.

## 6.11.2 Fiber Selection

The three major fiber parameters used in selecting the proper fiber for an application are bandwidth, attenuation and core diameter.

### Bandwidth

The bandwidth at a specified wavelength represents the highest sinusoidal light modulation frequency that can be transmitted through a length of fiber with an optical signal power loss equal to 50 percent (-3 dB) of the zero modulation frequency component. The bandwidth is expressed in megahertz over a kilometer length (MHz-km).

### Attenuation

The optical attenuation denotes the amount of optical power lost due to absorption and scattering of optical radiation at a specified wavelength in a length of fiber. It is expressed as an attenuation in decibels of optical power per kilometer (dB/km).

The attenuation is determined by launching a narrow spectral band of light into the full length of fiber and measuring the transmitted intensity. This measure is then repeated for the first 1.5 to 2.5 meters of the same fiber cable without disturbing the input end of the fiber. The dB/km attenuation is then calculated and normalized to 1 km.

### Core Diameter

The fiber core is the central region of an optical fiber whose refractive index is higher than that of the fiber cladding. Various core diameters are available to permit the most efficient coupling of light from commercially available light sources, such as LEDs or laser diodes.

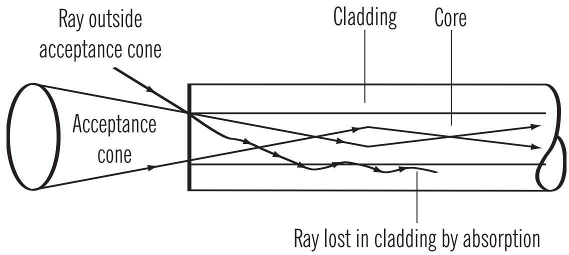


Figure 6.11–Optical Fiber Attenuation

## 6.11.3 Optical Fiber Cable Selection

Another important consideration when specifying optical fiber cable is the cable construction. Proper selection depends on the environment in which the cable will be installed. One of two different types of cable construction are generally employed to contain and protect the optical fibers.

### Loose Buffer

The first is a loose buffer tube construction where the fiber is contained in a water-blocked polymer tube that has an inner diameter considerably larger than the fiber itself. This provides a high level of isolation for the fiber from external mechanical forces that might be present on the cable. For multifiber cables, a number of these tubes, each containing one or more fibers, are combined with the necessary longitudinal strength member. Loose buffer cables are typically used in outdoor applications and can accommodate the changes in external conditions (e.g., contraction in cold weather and elongation in warm weather).

### Tight Buffer

The second cable construction is a tight buffer tube design. Here, a thick buffer coating is placed directly on the fiber.

Both constructions have inherent advantages. The loose buffer tube construction offers lower cable attenuation from a given fiber, plus a high level of isolation from external forces. This means more stable transmission characteristics under continuous mechanical stress. The tight buffer construction permits smaller, lighter weight designs and generally yields a more flexible cable. A comparison of these two cable constructions is shown below.

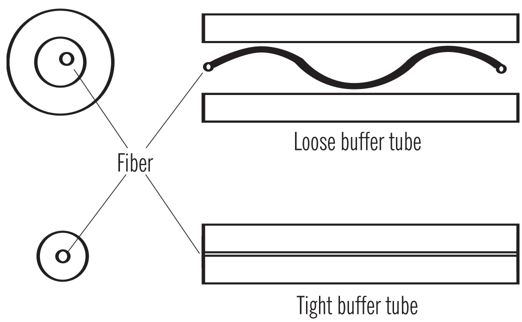


Figure 6.12–Optical Fiber Cable Designs

**Table 6.9–A Comparison of Loose Tube and Tight Buffer Optical Fiber Cable**

| Cable Parameter | Cable Construction | |
|---|---|---|
| | Loose Tube | Tight Buffer |
| Bend radius | Larger | Smaller |
| Diameter | Larger | Smaller |
| Tensile strength, installation | Higher | Lower |
| Impact resistance | Higher | Lower |
| Crush resistance | Higher | Lower |
| Attenuation change at low temperatures | Lower | Higher |

### Strength Members

Once the optical fiber is surrounded with a buffer, either loose or tight, strength members are added to the cable structure to keep the fibers free from stress and to minimize elongation and contraction. Such strength members provide tensile load properties similar to electronic cables and, in some cases, are used as temperature stabilization elements.

### Jacket

As with conventional metallic cables, the jacket protects the core from the external environment. With optical fibers, however, the selection of materials is influenced by the fact that the thermal coefficient of expansion of glass is significantly lower than that of the metal or plastic used in the cable structure.

### Installation

Normal cable loads sustained during installation or environmental movements first stress the strength members without transferring the stress to the optical fibers. If the load is increased, the fiber may ultimately be placed in a tensile stress state. This level of stress may cause microbending losses that result in attenuation increase and possibly fatigue effects.

## 6.12 TRAY CABLES

Tray cables are a special class of cables designed to meet stringent flame test requirements. A tray cable rating is given to a cable if it can meet the UL or CSA Standard for the rating. To obtain the rating, a cable must pass the 70,000 BTU, UL 1685 Vertical Tray Flame test or the Vertical Flame Test described in CSA C22.2 No. 0.3 (See Section 11.2 Fire Safety Tests for additional information).

In effect, a cable does not have a tray cable rating unless it is so marked, for example "for CT use" or "Type TC." Electrical inspectors will usually reject a cable even if it is capable of passing the tray cable fire test unless it is clearly marked on the cable as being a tray-rated cable.

A summary of applicable UL Standards, listings and markings is shown in Table 6.10. Note that, in some cases, the tray rating is an optional marking and is not an inherent part of the listing. Other UL and CSA Types that can be installed in tray in accordance with the NEC include CL2, CL2R, CL2P, CL3, CL3R, CL3P, CM, CMR, CMP, CMG, FPL, FPLR, FPLP, OFN, OFNR and OFNP.

**Table 6.10–Tray Cable Listings and Markings**

| Standard | UL Listings (Types) | Optional Markings |
| --- | --- | --- |
| UL 4 | AC | For CT use |
| UL 13 | PLTC | Direct burial<br>Sunlight resistant<br>ER (Exposed Run) |
| UL 44 | XHHW-2<br>RHW-2, RHH, RH<br>SIS, SA | For CT use<br>Sunlight resistant<br>Oil resistant<br>Pump cable |
| UL 444 | CM, CMR, CMP | Sunlight resistant |
| UL 1072 | MV | For CT use<br>Direct burial<br>Sunlight resistant<br>Oil resistant |
| UL 1277 | TC | Direct burial<br>Sunlight resistant<br>Oil resistant<br>ER (Exposed Run)<br>LS (Limited Smoke) |
| UL 1424 | FPL, FPLR, FPLP | Direct burial<br>Sunlight resistant<br>CI (Circuit Integrity)<br>Limited combustible<br>Wet location |
| UL 1425 | NPLF, NPLFR, NPLFP | Direct burial<br>Sunlight resistant<br>CI (Circuit Integrity)<br>Limited combustible<br>Wet location |
| UL 2250 | ITC | Direct burial<br>Sunlight resistant<br>Wet location |