6. CABLE TYPES AND SELECTION CRITERIA

CONTENTS

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6. CABLE TYPES AND SELECTION CRITERIA (CONT)

CONTENTS

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, SOW-A, SOOW-A, SJ, SJO, SJOW-A, STO** and **SJTO.** In portable cord terminology, each letter of the cable type indicates the construction of the cable. For example: S = stranded, O = oil resistant, J = junior service (300 V), 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-A 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

TS	Tinsel Service
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
SJT	Service Junior Thermoplastic
SJTO	SJT with Oil-Resistant Jacket
SJTOO	SJTO with Oil-Resistant Insulation
SJE	Service Junior Elastomer
SJEO	SJE with Oil-Resistant Jacket
SJEOO	SJEO with Oil-Resistant Insulation
S	Service

Continued

Table 6.1–Flexible cord type designations

Continued

SO	Service with Oil-Resistant Jacket
SOO	SO with Oil-Resistant Insulation
ST	Service Thermoplastic
STO	ST with Oil-Resistant Jacket
STOO	STO with Oil-Resistant Insulation
SE	Service Elastomer
SEO	SE with Oil-Resistant Jacket
SEOO	SEO with Oil-Resistant Insulation
HPN	Heater Parallel Neoprene
HSJ	Heater Service Junior
HSJO	HSJ with Oil-Resistant Jacket
HS	Heater Service
HSO	HS 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.

6.3 Control, Instrumentation, and Thermocouple

6.3.1 Control

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.

A typical 600 volt control cable is shown below:

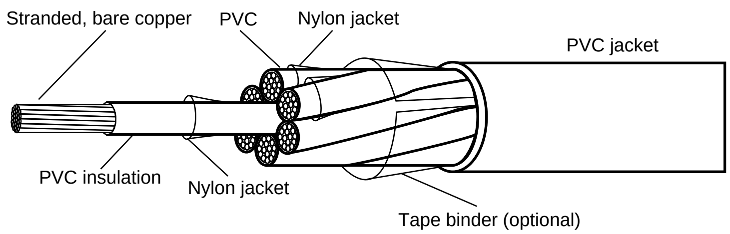


Figure 6.1–A typical 600 volt control cable

6.3.2 Instrumentation

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.

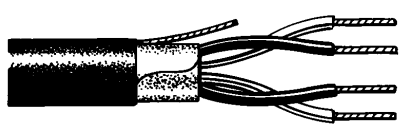


Figure 6.2–Control cable with overall shield

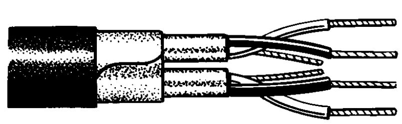


Figure 6.3–Control cable with individually shielded pairs and an overall shield

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 instrumentation senses this voltage and converts it to temperature.

Thermocouple wire or **extension grade wire** is recommended for use in connecting thermocouples to the sensing or control instrumentation. 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.

Thermocouple Types

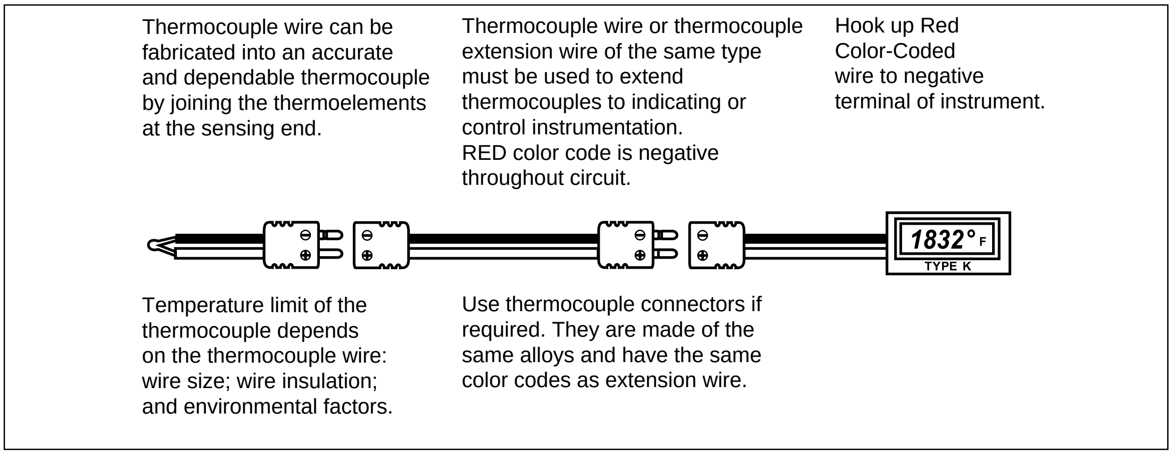
Type J (**Iron vs Constantan**) is used in vacuum, oxidizing, inert or reducing atmospheres. Iron oxidizes rapidly at temperatures exceeding 538°C (1,000°F), and therefore heavier gauge wire is recommended for longer life at these temperatures.

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 N (**Nicrosil vs Nisil**) is used in oxidizing, inert or dry reducing atmospheres. Must be protected from sulfurous atmospheres. Very reliable and accurate at high temperatures.



Source: PMC Corporation

Figure 6.4 – A typical thermocouple circuit

Table 6.2 – Color code for thermocouple wire

Thermocouple Type		Color Code
Wire Alloys	**ANSI Symbol**	**+/– Individual**
*Iron (+) vs Constantan (–)	J	White/Red
Chromel (+) vs *Alumel (–)	K	Yellow/Red
Copper (+) vs Constantan (–)	T	Blue/Red
Chromel (+) vs Constantan (–)	E	Purple/Red
Nicrosil (+) vs Nisil (–)	N	Orange/Red

*Magnetic

Table 6.3 – Color code for thermocouple extension wire

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
Nicrosil vs Nisil	NX	Orange/Red	Orange

*Magnetic

6.4 High Temperature

The term "high temperature" generally refers to wire or cable with a temperature rating of 125°C (302°F) or higher. However, depending on your point of reference, the ratings can be as low as 90°C (194°F). Below are listed some of the most common **high temperature wire and cable** types along with their temperature rating:

Table 6.4 –High temperature cable ratings chart

°C	°F	Type
1,000	1,832	Heating Cable: Type 2
538	1,000	Apparatus and Motor Lead Wire: **MG** (Non-UL)
450	842	Appliance and Fixture Wire: MG (UL)
400	752	Heating Cable: Type 1
250	482	Apparatus and Motor Lead Wire: MG, **TGGT, TKGT** Appliance and Fixture Wire: **HRSR, MG, TGGT, TKGT, TGC** Instrumentation Cable: TKGT, **TKGK** Control Cable: TKGT, **TMMG,** TKGK Power Cable: TKGK, **TMKS,** TMMG Heating Cable: **SRG, PFA**
230	446	Appliance and Fixture Wire: HRSR
200	392	Apparatus and Motor Lead Wire: **KK**, SRG, **SRK, SRGT** (Hot Spot) Appliance and Fixture Wire: **KG, SR,** SRG, SRK, **TE, HVSR, TGS** Heating Cable: Type 9 Thermocouple Cable: **SRGK, SRGS** Instrumentation Cable: SRGK, SRGS Control Cable: SRGK, SRGS, SRGT, SRGT **K,** SRGT S Power Cable: SRGK, SRGS, SRGT, SRK, SRGT L, SRGT S Fire Alarm Cable: **SSFA**
150	302	Apparatus and Motor Lead Wire: KK, SRG, **XLPO** Thermocouple Cable: SRGK Appliance and Fixture Wire: HVSR, K, KG, KK, SR, SRG, TE, XLPO, TGS Instrumentation Cable: SRGK, SRGT F, SRGS Control Cable: SRGK, SKSM, SRGT F, SRGS Power Cable: **SKSM**, SRGK, SRGT F, SRGS
125	257	Apparatus and Motor Lead Wire: SRK, **XPT, XXT** Appliance and Fixture Wire: **FREP**, XPT, XXT

Continued

Table 6.4 –Temperature ratings chart

Continued

°C	°F	Type
105	221	Thermocouple Cable: PV*****X, SGNV, SRNV, PX*****X Instrumentation Cable: **SGNV, SRNV, PVIC, PZIC** Fire Alarm Cable: **SVFA**
90	194	Switchboard Wire: **SIS,** VW-1, SIS Thermocouple Cable: FREP-CPE, **FREP-II** Instrumentation Cable: **FREP-CPE,** FREP-II, SRGT/V, SRGT/C Control Cable: FREP-CPE, FREP-II, SRGT/V, SRGT/C Power Cable: FREP-CPE, FREP-II, SRGT/V, SRGT/C

*Insert **J**, **K**, **T**, **E** or **N** depending upon thermocouple type.

6.5 Power

Below are some of the key factors that influence the choice of **power cable:**

- System voltage rating.
- Current loading requirements.
- External thermal conditions such as ambient temperature, proximity of other cables, adjacent sources of heat, thermal conductivity of soil, etc.
- Voltage drop considerations.
- 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 neutral service (**100 percent insulation level**), and ungrounded neutral service (**133 percent insulation level**).

In case of a phase to ground fault, it is possible to operate **ungrounded systems** for up to one hour with one phase conductor at ground potential. This condition results in full line-to-line voltage stress across the insulation of each of the other two phase conductors. For this reason each phase conductor of such a cable has 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.

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, assuming a 40°C ambient temperature, a three-conductor 4/0 copper, 15 kV, XLPE insulated cable in an overhead cable tray in open air will carry 325 amperes. The same cable installed in a conduit in air will only carry 289 amperes.

Running a single conductor cable through a magnetic conduit will increase the apparent resistance of the cable and will result in a lower current-carrying capacity due to the additional resistance and magnetic losses.

Similarly, when cables are run close together the presence of the other cables, in effect, increases the ambient temperature, which decreases the ability of the cable to dissipate its heat. As a result, many conditions must be known before an accurate current-carrying capacity can be assigned to a particular cable installation.

Occasionally, emergency overload conditions are involved and these may also 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 carry. The construction of cable is such that its mechanical strength is high and it can handle short-circuit currents without any mechanical difficulty. From a thermal standpoint, however, there is a limit to the amount of short-circuit current which can be carried.

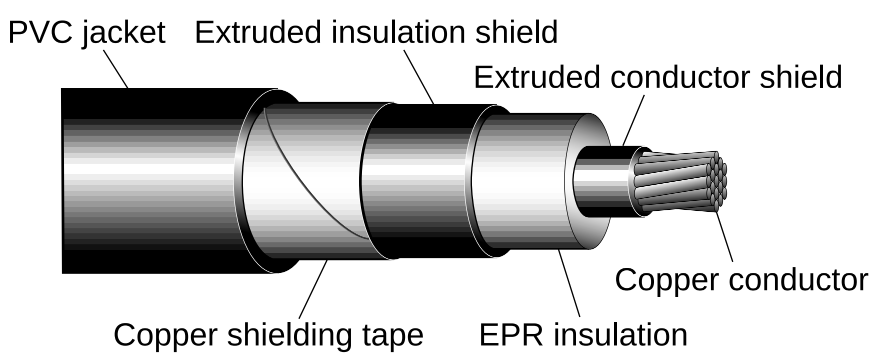


Figure 6.5 – Typical tape shielded 15 kV power cable

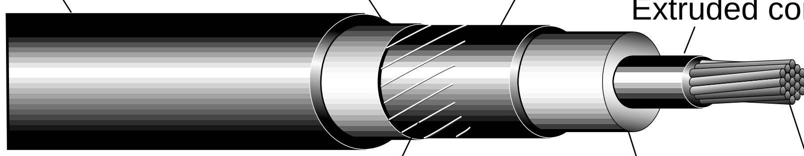


Figure 6.6 – Typical wire shielded 15 kV power cable

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 which 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 reagents 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 Chapter 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 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.

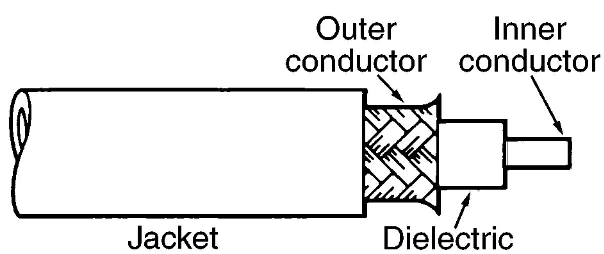


Figure 6.7–Typical coaxial cable

Nominal Impedance. The nominal or **characteristic impedance** of a coaxial cable is a function of its geometry and materials. Nominal impedance for coax ranges from 35 to 185 ohms; the most common values are 50, 75, and 93 ohms.

The most efficient transfer of energy from a source to a load occurs when all parts of the system have the same 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 nominal 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% means that the energy travels at 120,900 miles per second—or 35% slower than in free space.

The dielectric 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 rating specifies the maximum voltage the cable is designed to handle.

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

Types of Coaxial Cables. The following paragraphs briefly identify the common types of coaxial cable available.

Flexible Coax. The most common type, flexible cables use 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 supplement the braid to provide better coverage for greater shielding effectiveness. The greater the coverage, the better the shield.

Semirigid Coax. Semirigid cables have a solid, tubular outer conductor, similar to a pipe. This construction gives the cable a very uniform impedance (low VSWR) and excellent shielding, but at the expense of flexibility.

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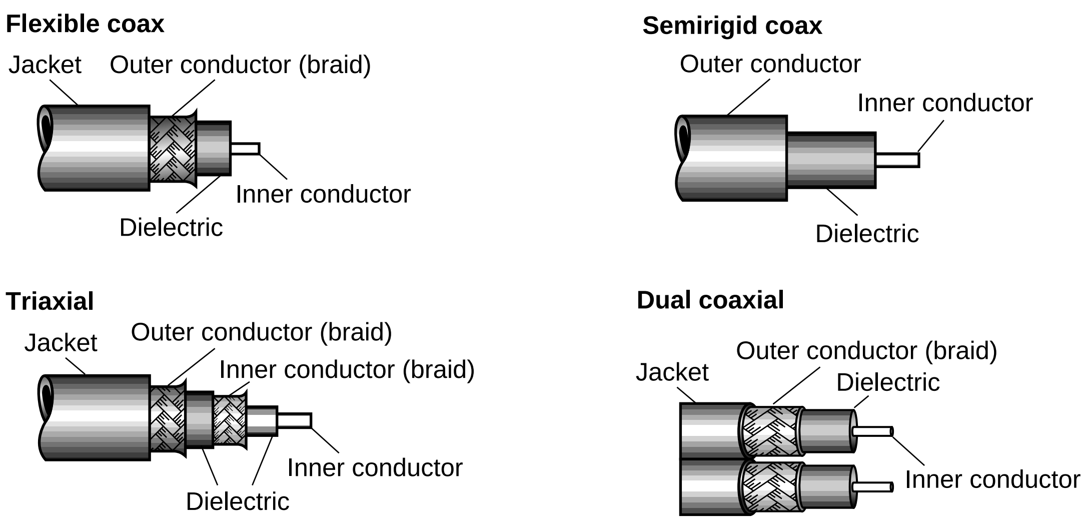
Triaxial Cable. This cable has two outer conductors (shields) separated by a dielectric layer. One outer conductor (shield) serves as a signal ground, while the other serves as earth ground, providing better noise immunity and shielding. One caution: **Do not confuse** a flexible cable having a multilayer outer shield with triaxial cable.

Dual Coaxial Cable. This cable contains two individual coaxial cables surrounded by a common outer jacket.

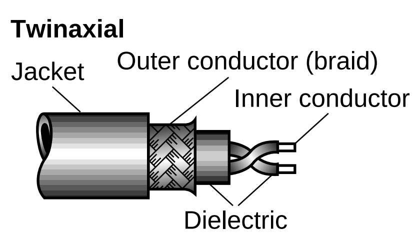


Figures 6.8 – 6.11–Common types of coaxial cable

6.7.2 Twinax Cable

Twinax cable 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 cable 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 6.12 –A typical twinaxial cable

6.7.3 UTP and STP

Unshielded Twisted Pair (UTP) and **Shielded Twisted Pair** (STP) are low pair count cables (usually 2 to 8 pairs) that have been designed for use in local area networks such as **Token Ring, Ethernet,** etc. Because of their relatively low cost these cable types are widely used and are available in several different performance categories (levels)—**Categories 3, 4** and **5.** Attenuation, crosstalk and impedance are specified in EIA/TIA-568. An overview of their electrical requirements are shown below.

Table 6.5 –Twisted pair cable performance categories

Category	Impedance	Attenuation dB/1000 ft	NEXT*	Mutual Capacitance Maximum
3 LAN & Medium Speed Data	100 ohm ± 15% 1–16 MHz	7.8 @ 1 MHz 17 @ 4 MHz 30 @ 10 MHz 40 @ 16 MHz	41 dB @ 1 MHz 32 dB @ 4 MHz 26 dB @ 10 MHz 23 dB @ 16 MHz	20 pF/ft
4 Extended Distance LAN	100 ohm ± 15% 1–20 MHz	6.5 @ 1 MHz 13 @ 4 MHz 22 @ 10 MHz 27 @ 16 MHz 31 @ 20 MHz	56 dB @ 1 MHz 47 dB @ 4 MHz 41 dB @ 10 MHz 38 dB @ 16 MHz 36 dB @ 20 MHz	17 pF/ft
5 High Speed LAN	100 ohm ± 15% 1–100 MHz	6.3 @ 1 MHz 13 @ 4 MHz 20 @ 10 MHz 25 @ 16 MHz 28 @ 20 MHz 32 @ 25 MHz 36 @ 31.25 MHz 52 @ 62.5 MHz 67 @ 100 MHz	62 dB @ 1 MHz 53 dB @ 4 MHz 47 dB @ 10 MHz 44 dB @ 16 MHz 42 dB @ 20 MHz 41 dB @ 25 MHz 40 dB @ 31.25 MHz 35 dB @ 62.5 MHz 32 dB @ 100 MHz	17 pF/ft

*Worst pair near end crosstalk

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Unshielded Twisted Pair (UTP) vs Shielded Twisted Pair (STP)
There are two basic types of **electromagnetic interference** (**EMI**) that cable engineers worry about—**electromagnetic *emissions*** and **electromagnetic *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 (STP) 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** of cable, the better the cable is electrically balanced. **Category 5 cable** has more twists per foot than Category 3 or 4 cables and, therefore, offers better protection from EMI problems.

6.7.4 IBM Cabling System

In the 1980s, IBM developed the IBM Cabling System. It is designed to be used as a "structured" building wiring system that is compatible with all other **IEEE 802.5** networks and equipment. Details of cable types, cable performance requirements, test methods, quality requirements and accessories are contained in the document "IBM Cabling System Technical Interface Specification" published by IBM. It covers the following IBM cable types:

Table 6.6 –IBM cable types

Cable Type	Construction and (Identifier)	Spec. No.
Type 1, Non-plenum	2-#22 AWG CU TP (NP)	4716748
Type 1, Plenum	2-#22 AWG CU TP (P)	4716749
Type 1, Riser	2-#22 AWG CU TP (R)	6339585
Type 1, Outdoor	2-#22 AWG CU TP (OD)	4716734
Type 2, Non-plenum	2-#22 AWG CU TP (NP) 4-#22 AWG CU TP (VGM)	4716739
Type 2, Plenum	2-#22 AWG CU TP (P) 4-#22 AWG CU TP (VGM)	4716738
Type 3, Telephone Twisted Pair	2-#22 or 24 AWG CU TP	AT&T 403595051 or equivalent
Type 5, Fiber Optic	2-100/140µm fibers (OFM)	4716744
Type 6, Non-plenum	2-#26 AWG CU TP ST (NPO)	4716743
Type 8, Undercarpet	2-#26 AWG CU FP (UC)	4716750
Type 9, Plenum	2-#26 AWG CU TP (P)	6339583

6.8 Telephone

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

With the advent of fiber optic 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 3600 pair "exchange" cables, which are typically installed between central offices of the telephone company.

Exchange cables, because they are often installed in underground ducts or directly buried in the earth, are designed with various combinations of polyethylene (PE) jacket(s) 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 µF 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 ¼-in. 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 (sometimes called "IC") cable. 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 since it often extends to the exterior of the building. True inside cable, on the other hand, is typically larger (25 to 600 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 or UL 910).

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 (ohms per loop-mile), crosstalk (decibel isolation between pairs), and attenuation (decibels per mile). When used for high speed digital applications, characteristic impedance (ohms) 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 hookup and lead wire, airframe wire, control cable and coax. A **mil-spec wire** or cable must meet rigorous performance requirements. Tests which 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-W-76	General purpose hookup wire, PVC insulated
MIL-W-5845	Thermocouple wire, iron and constantan
MIL-W-5846	Thermocouple wire, chromel and alumel
MIL-W-8777	Aircraft wire, silicone insulated
MIL-W-16878	General purpose hookup and lead wire
MIL-W-25038	Aircraft wire, inorganic fibrous/teflon insulation, high temperature and fire resistant, engine zone wire
MIL-W-81822	Solderless wrap (**wire wrap**), for use around terminal pins, Kynar, TFE, TEFZEL, TFE/Polyimide, PVC, FEP or Mylar insulated, also available uninsulated
MIL-C-915	Shipboard cable, inactive for new design except outboard types
MIL-C-3432	Power and special purpose cables used for ground support systems ("CO" types)
MIL-C-5756	Cable and wire, portable power, rubber insulated
MIL-C-7078	Cable, aerospace vehicle, Irradiated Polyalkene/Kynar, PVC, Kapton, Teflon insulated
MIL-C-13294	Field wire, WD-1/TT
MIL-C-13486	Cable, special purpose, low tension, single and multiconductor ordinance, neoprene or Hypalon
MIL-C-13777	Cable, ground support, polyethylene insulation, neoprene jacket
MIL-C-24640	**Shipboard cable**, lightweight
MIL-C-24643	Shipboard cable, low smoke
MIL-C-27072	Cable, special purpose, multiconductor ground support, for electronic circuits, PVC or Teflon insulated
MIL-C-27500	**Aerospace** and other general application wire

Continued

Continued

Type	Description
MIL-C-47206	Cable, single conductor, twisted pairs, and multiconductor, high temperature; PVC and Teflon insulated
MIL-C-49055	Cable, power, flat, PVC, Tefzel, TFE and FEP insulated
MIL-C-55021	Cable, twisted pairs and triples, internal hookup, PVC and Teflon insulated
MIL-I-23053	**Tubing, heat shrink**
MIL-I-22129	Tubing, nonshrink

6.10 Shipboard Cables (MIL-C-24643, MIL-C-24640 and MIL-C-915)

Due to concern about flammability, smoke, and toxicity, the U.S. Navy introduced the MIL-C-24643 cable specification. Generally, this document provides low smoke, flame retardant cables that are approximately equivalent in size, weight, and electricals to many of the older MIL-C-915 constructions. It has been mandated that these cables must be used on all new constructions and major Navy ship modernization projects.

In consideration of circuit density, weight, and size, the U.S. Navy produced the MIL-C-24640 cable document. The cables covered by this specification are also low smoke, flame resistant constructions, but they are significantly lighter in weight and smaller in diameter. MIL-C-24640 cables are used to interconnect systems where weight and space savings are critical; however, they are not direct replacements.

Since the overall diameters have been reduced and electrical characteristics may have been changed, they should not be used to replace existing MIL-C-915 or MIL-C-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-C-915.

Additionally, cables jacketed with polyvinyl chloride presented the dangers of toxic fumes and dense, impenetrable smoke when undergoing combustion. These hazards became increasingly evident when an electrical fire smoldered through the cableways aboard the DDG 19 (*USS Tattnall*). Due to the overwhelming amount of smoke and fumes, firefighters were unable to effectively control the fire and a large amount of damage resulted. A family of low smoke, low toxicity cable, constructed with a polyolefin jacket rather than a polyvinyl chloride jacket, conforms to rigid toxic and smoke indexes to effectively reduce the hazards associated with PVC jacketed cables. The low smoke cable is covered by military specification MIL-C-24643.

A family of lightweight cables was also introduced to aid in the elimination of excessive weight from the fleet. Considering the substantial amount of cable present on a ship or submarine, a reduction in cable weight will have a considerable impact on the overall load, thus improving performance and increasing efficiency. This new family of lightweight cables is constructed from cross-linked polyalkene and mica-polyimide insulation and a cross-linked polyolefin jacket. The lightweight cable is covered by military specification MIL-C-24640.

6.11 Optical Fiber Cables

In all types of optical fiber cables, the individual optical fibers are the signal transmission media which act as individual optical wave guides. The fibers consist of a central transparent **core** region which 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. PCS (plastic clad silica) fiber, with a **glass core** and **plastic cladding,** and all-plastic fibers are available for special applications. To achieve high signal bandwidth capabilities, the core region sometimes has a varying (or graded) **refractive index.**

6.11.1 Fiber Types

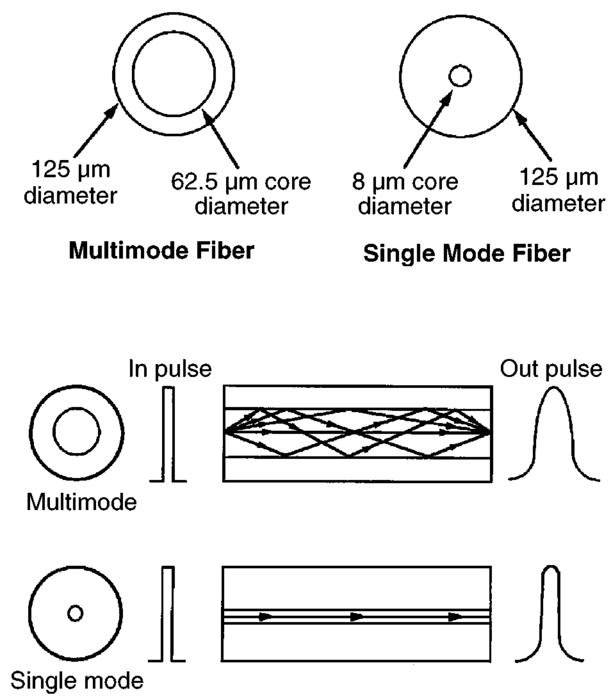

Figure 6.13 – Optical fiber types

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 (i.e., interstate) and high bandwidth (information carrying capacity) applications. Multimode, on the other hand, has a core diameter of 50, 62.5 or 100 microns (62.5 being the most common) and is usually used intrabuilding.

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 optical radiation wavelength represents the highest sinusoidal light modulation frequency which can be transmitted through a length of fiber with an optical signal power loss equal to 50 percent (−3dB) 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.

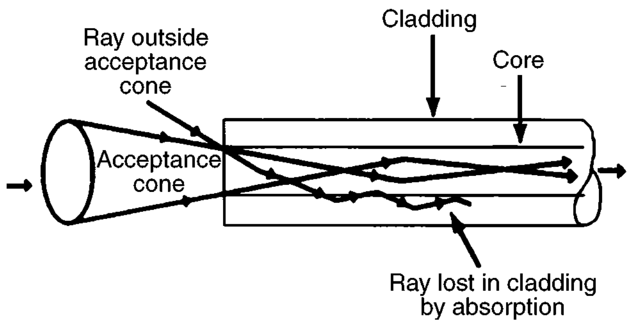

Figure 6.14 –Optical fiber attenuation

6.11.3 Optical Fiber Cable Selection

Another important consideration when specifying fiber optic cable is the *cable* construction. Proper selection depends on the environment in which the cable will be installed.

Loose Buffer

Two different types of cable construction are generally employed to contain the optical fibers. The first is a loose buffer tube construction where the fiber is contained in a gel-filled 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 is used in outdoor applications and can accommodate the changes in external conditions (i.e., contraction in cold weather and elongation in warm weather).

Tight Buffer

The second cable construction is a tight buffer design, usually used in indoor applications. Here, a thick buffer coating is placed directly on the fiber. This type of buffer provides excellent protection against bending and offers better crush resistance than does a loose buffer.

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.

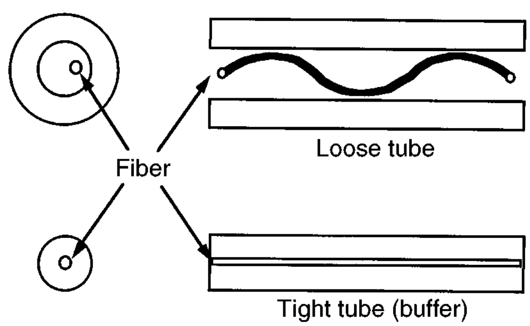

Figure 6.15 –Optical fiber cable designs

Table 6.7–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 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 which 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 1581 **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).

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 6.8. 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 6.8 – Tray cable listings and markings

Standard	UL Listings (Types)	Optional Markings
UL 4	AC	"for CT use"
UL 13	PLTC	"Direct burial" "Sunlight resistant"
UL 44	XHHW-2 RHW-2, RHH, RH SIS, SA	"For CT use" "Sunlight resistant" "Oil resistant" "Pump Cable"
UL 1072	MV	"for CT use" "Direct burial" "Sunlight resistant" "Oil resistant"
UL 1277	TC	"Direct burial" "Sunlight resistant" "Oil resistant"
UL 1569	MC	"for CT use" "Direct burial" "Sunlight resistant" "Oil resistant"