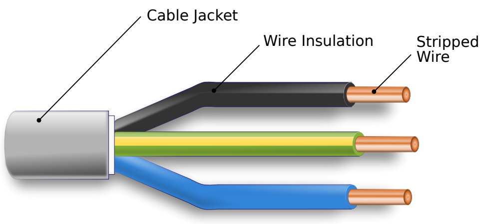
Contents

Chapter 1

Cable

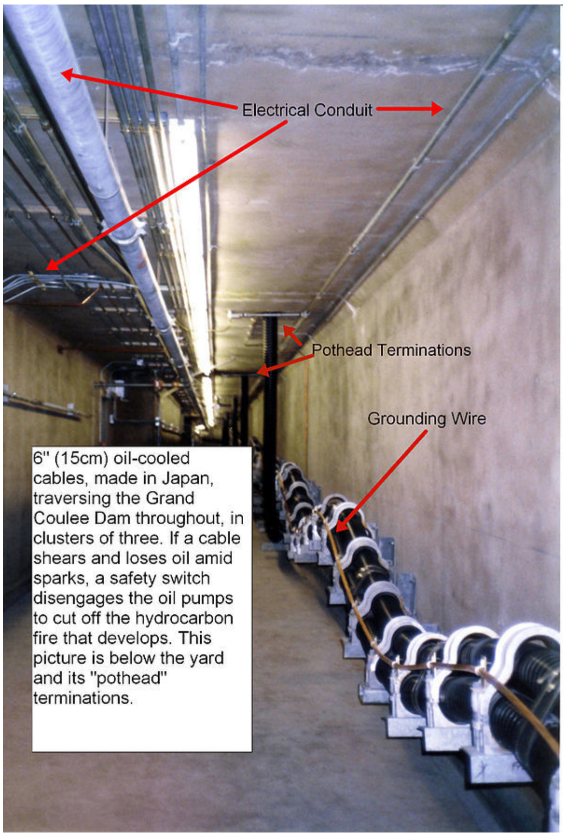
This article is about electrical cables. For other uses, see Cable (disambiguation).

An electrical **cable** comprises two or more wires running side by side and bonded, twisted, or braided together to form a single assembly, the ends of which can be connected to two devices, enabling the transfer of electrical signals from one device to the other. Cables are used for a wide range of purposes, and each must be tailored for that purpose. Cables are used extensively in electronic devices for power and signal circuits. Long-distance communication takes place over undersea cables. Power cables are used for bulk transmission of alternating and direct current power, especially using high-voltage cable. Electrical cables are extensively used in building wiring for lighting, power and control circuits permanently installed in buildings. Since all the circuit conductors required can be installed in a cable at one time, installation labor is saved compared to certain other wiring methods.



Electrical cable cross section

The term originally referred to a nautical line of specific length where multiple ropes, each laid clockwise, are then laid together anti-clockwise and shackled to produce a strong thick line, resistant to water absorption, that was used to anchor large ships. In mechanics, cables, otherwise known as wire ropes, are used for lifting, hauling, and towing or conveying force through tension. In electrical engineering cables are used to carry electric currents. An optical cable contains one or more optical fibers in a protective jacket that supports the fibers.



6 inch (15 cm) outside diameter, oil-cooled cables, traversing the Grand Coulee Dam throughout. An example of a heavy cable for power transmission.

1.1 Etymology

Ropes made of multiple strands of natural fibers such as, hemp, sisal, manila, and cotton have been used for millennia for hoisting and hauling. By the 19th century, deeper mines as well as construction of larger and larger sailing ships increased demand for stronger ropes. In 1830 the Royal Navy defined a cable as three hawser laid (clockwise) ropes, each approximately 120 fathoms in length, laid anti-clockwise, tightly twisted and shackled to a resulting length of approximately 100 fathoms. The tight twists, shortened the overall length of the ropes but both strengthened the ropes and reduced the ability of the rope to absorb water making them ideal for mooring.[1][2]

Improvements to steelmaking techniques made high-quality steel available at lower cost, and so wire ropes became common in mining and other industrial applications while continuing the practice of anti-cyclical twists to strengthen them even further. By the middle of the 19th century, manufacture of large submarine telegraph cables was done using machines similar to those used for manufacture of mechanical cables. As the move from rope to wire happened, the specific length associated with a cable fell into disuse.

As electricity became more and more ubiquitous the practice of using more than bare copper led to groupings of wires and various sheathing and shackling methods that resembled the mechanical cabling so the term was adopted for electrical wiring. In the 19th century and early 20th century, electrical cable was often insulated using cloth, rubber or paper. Plastic materials are generally used today, except for high-reliability power cables. The term has also come to be associated with communications because of its use in electrical communications.

1.2 Electrical cables

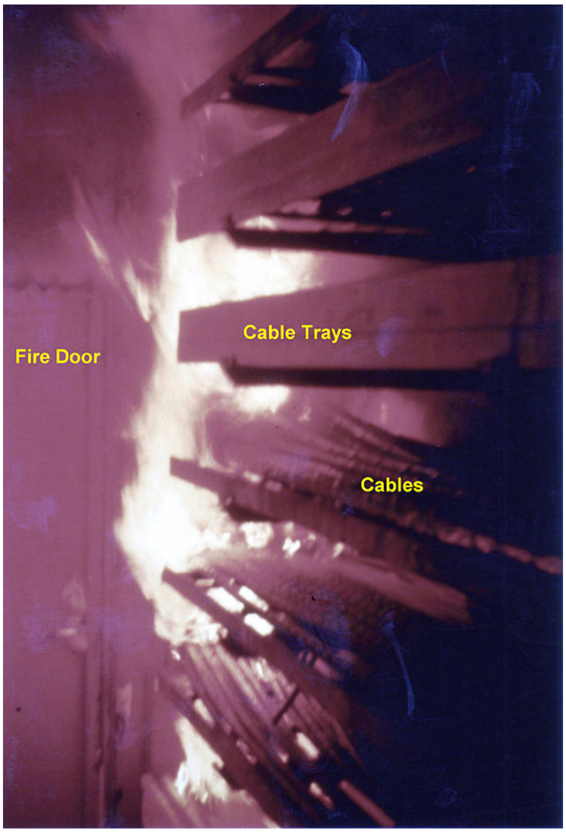
Electrical cable is an assembly consisting of one or more conductors with their own insulations and optional screens, individual covering(s), assembly protection and protective covering(s). Electrical cables may be made more flexible by stranding the wires. In this process, smaller individual wires are twisted or braided together to produce larger wires that are more flexible than solid wires of similar size. Bunching small wires before concentric stranding adds the most flexibility. Copper wires in a cable may be bare, or they may be plated with a thin layer of another metal, most often tin but sometimes gold, silver or some other material. Tin, gold, and silver are much less prone to oxidation than copper, which may lengthen wire life, and makes soldering easier. Tinning is also used to provide lubrication between strands. Tinning was used to help removal of rubber insulation. Tight lays during stranding makes the cable extensible (CBA – as in telephone handset cords).

Cables can be securely fastened and organized, such as by using trunking, cable trays, cable ties or cable lacing. Continuous-flex or flexible cables used in moving applications within cable carriers can be secured using strain relief devices or cable ties.

At high frequencies, current tends to run along the surface of the conductor. This is known as the skin effect.

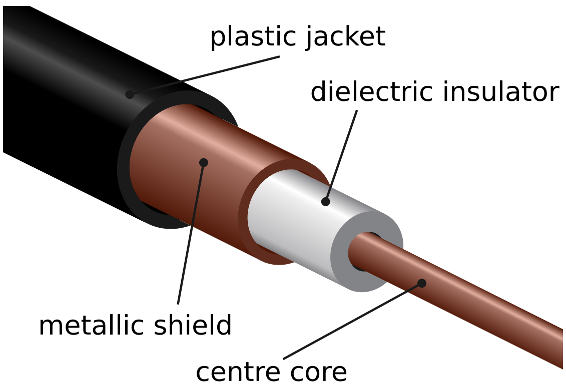
1.2.1 Cables and electromagnetic fields

Any current-carrying conductor, including a cable, radiates an electromagnetic field. Likewise, any conductor or cable will pick up energy from any existing electromagnetic field around it. These effects are often undesirable, in the first case amounting to unwanted transmission of energy which may adversely affect nearby equipment or



Fire test in Sweden, showing rapid fire spread through burning of cable jackets. Of great importance for cables used in installations.

500,000 circular mil (254 mm^2) single conductor power cable



Coaxial cable

Twisted pair cabling

other parts of the same piece of equipment; and in the second case, unwanted pickup of noise which may mask the desired signal being carried by the cable, or, if the cable is carrying power supply or control voltages, pollute them to such an extent as to cause equipment malfunction.

The first solution to these problems is to keep cable lengths in buildings short, since pick up and transmission are essentially proportional to the length of the cable. The second solution is to route cables away from trouble. Beyond this, there are particular cable designs that minimize electromagnetic pickup and transmission. Three of the principal design techniques are shielding, coaxial geometry, and twisted-pair geometry.

Shielding makes use of the electrical principle of the Faraday cage. The cable is encased for its entire length in foil or wire mesh. All wires running inside this shielding layer will be to a large extent decoupled from external electric fields, particularly if the shield is connected to a point of constant voltage, such as earth. Simple shielding of this type is not greatly effective against low-frequency magnetic fields, however - such as magnetic "hum" from a nearby power transformer. A grounded shield on cables operating at 2.5 kV or more gathers leakage current and capacitive current, protecting people from electric shock and equalizing stress on the cable insulation.

Coaxial design helps to further reduce low-frequency magnetic transmission and pickup. In this design the foil or mesh shield has a circular cross section and the inner conductor is exactly at its center. This causes the voltages induced by a magnetic field between the shield and the core conductor to consist of two nearly equal magnitudes which cancel each other.

A twisted pair has two wires of a cable twisted around each other. This can be demonstrated by putting one end of a pair of wires in a hand drill and turning while maintaining moderate tension on the line. Where the interfering signal has a wavelength that is long compared to the pitch of the twisted pair, alternate lengths of wires develop opposing voltages, tending to cancel the effect of the interference.

1.2.2 Fire protection

In building construction, electrical cable jacket material is a potential source of fuel for fires. To limit the spread of fire along cable jacketing, one may use cable coating materials or one may use cables with jacketing that is inherently fire retardant. The plastic covering on some metal clad cables may be stripped off at installation to reduce the fuel source for fires. Inorganic coatings and boxes around cables safeguard the adjacent areas from the fire threat associated with unprotected cable jacketing. However, this fire protection also traps heat generated from conductor losses, so the protection must be thin.

To provide fire protection to a cable, the insulation is treated with fire retardant materials, or non-combustible mineral insulation is used (MICC cables).

1.2.3 Electrical cable types

A 250 V, 16 A electrical cable on a reel.

- Coaxial cable: used for radio frequency signals, for example in cable television distribution systems.
- Communications cable
- Direct-buried cable
- Flexible cables
- Heliax cable
- Non-metallic sheathed cable (or nonmetallic building wire, NM, NM-B)[3]
- Metallic sheathed cable (or armored cable, AC, or BX)[3]
- Multicore cable (consist of more than one wire and is covered by cable jacket)
- Paired Cable: Composed of two individually insulated conductors that are usually used in DC or low-frequency AC applications

- Ribbon cable: Useful when many wires are required. This type of cable can easily flex, and It is designed to handle low-level voltages.
- Shielded cable: used for sensitive electronic circuits or to provide protection in high-voltage applications.
- Single cable (from time to time this name is used for wire)
- Submersible cable
- Twinax cable
- Twin-lead: This type of cable is a flat two-wire line. It is commonly called a 300 Ω line because the line has an impedance of 300 Ω. It is often used as a transmission line between an antenna and a receiver (e.g., TV and radio). These cables are stranded to lower skin effects.
- Twisted pair: Consists of two interwound insulated wires. It resembles a paired cable, except that the paired wires are twisted

1.3 Hybrid cables

Hybrid optical and electrical cables can be used in wireless outdoor fiber-to-the-antenna (FTTA) applications. In these cables, the optical fibers carry information, and the electrical conductors are used to transmit power. These cables can be placed in several environments to serve antenna mounted on poles, towers or other structures.

According to Telcordia GR-3173, *Generic Requirements for Hybrid Optical and Electrical Cables for Use in Wireless Outdoor Fiber To The Antenna (FTTA) Applications,* these hybrid cables are intended to carry optical fibers, twisted pair/quad elements, coaxial cables or current-carrying electrical conductors under a common outer jacket. The power conductors used in these hybrid cables are for directly powering an antenna or for powering tower-mounted electronics exclusively serving an antenna. They have a nominal voltage normally less than 60 VDC or 108/120 VAC.[4] However, other voltages may be present depending on the application and the relevant National Electrical Code (NEC).

Since the voltage levels and power levels used within these hybrid cables vary, for the purposes of applicable codes, the hybrid cable shall be considered a power cable. As noted in GR-3173, from an NESC perspective (i.e., IEEE C2, *National Electrical Safety Code® [NESC®]*), since these cables are not communications cables and are not power limited, they are considered power cables and need to comply with clearance, separation, and other safety rules.

1.4 Mechanical cables

- Arresting cable
- Bowden cable
- Heavy-lift cable
- Wire rope (wire cable)

1.5 See also

For transmission see: Power cable, High-voltage cable and HVDC

- Cable dressing
- Cable gland
- Cable harness
- Cable lacing
- Cable length
- Cable management
- Cable modem
- Cable reel
- Cable television
- Cable tray
- Category 5 cable
- Category 6 cable
- Category 7 cable
- Circuit integrity
- Copper wire and cable
- Cross-linked polyethylene
- DOCSIS
- Electrical connector
- Electrical wiring
- Extension cable
- International Cablemakers Federation
- Over/under cable coiling
- Polyvinyl chloride
- Portable cord
- Power cable
- Profibus

- Submarine communications cable
- Submarine power cable
- Steel Wire Armoured (SWA) Cable
- SY control cable
- Tensile structure
- Transmission line
- Underwriter's knot
- Wire
- Wire rope

1.6 References

[1] Richard Sheppard. "Glossary of Nautical Measures - Lengths - Hemyock Castle". *hemyockcastle.co.uk*.

[2] International Maritime Dictionary by Rene & Kerchove, published 1961, Van Nostrand Reinheld Co.

[3] "Electrical Wiring FAQ (Part 2 of 2)Section - What is Romex/NM/NMD? What is BX? When should I use each?". *faqs.org*.

[4] GR-3173-CORE, *Generic Requirements for Hybrid Optical and Electrical Cables for Use in Wireless Outdoor Fiber To The Antenna (FTTA) Applications,* Telcordia.

1.7 Further reading

- R. M. Black, *The History of Electric Wires and Cables*, Peter Pergrinus, London 1983 ISBN 0-86341-001-4
- BICC Cables Ltd, "Electric Cables Handbook", WileyBlackwell; London 3rd Edition 1997, ISBN 0-632-04075-0
- GR-421-CORE, *Generic Requirements for Metallic Telecommunications Cables,* Telcordia.

1.8 External links

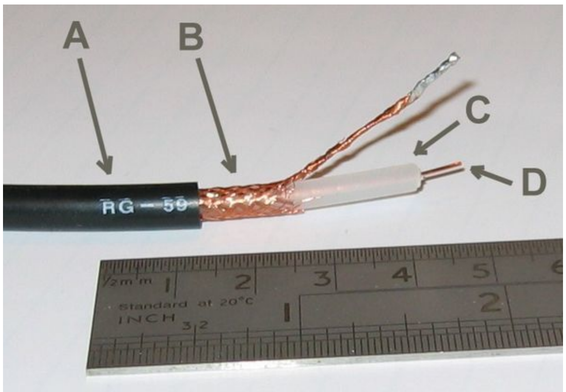
- Cable Jacket Types Explained w/ Reference Chart

Chapter 2

Coaxial cable

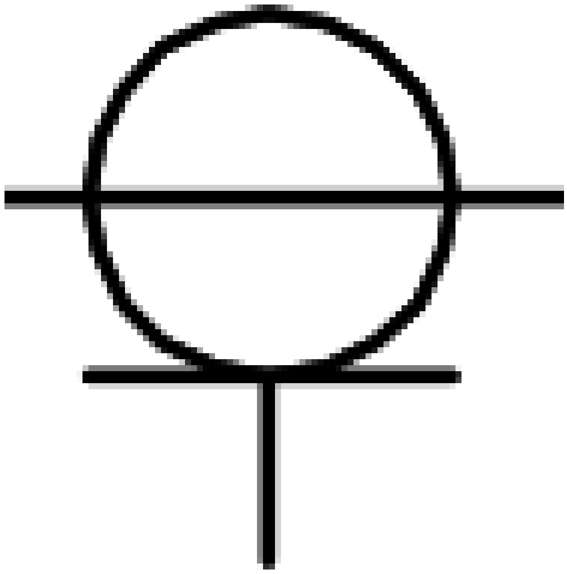
“Coax” redirects here. For the act of coaxing, see Persuasion.

Coaxial cable, or **coax** (pronounced /ˈkoʊ.æks/), is a type of cable that has an inner conductor surrounded by a tubular insulating layer, surrounded by a tubular conducting shield. Many coaxial cables also have an insulating outer sheath or jacket. The term coaxial comes from the inner conductor and the outer shield sharing a geometric axis. Coaxial cable was invented by English engineer and mathematician Oliver Heaviside, who patented the design in 1880.[1] Coaxial cable differs from other shielded cable used for carrying lower-frequency signals, such as audio signals, in that the dimensions of the cable are controlled to give a precise, constant conductor spacing, which is needed for it to function efficiently as a radio frequency transmission line.



RG-59 ***flexible coaxial cable*** *composed of:*

1. *Outer plastic sheath*
2. *Woven copper shield*
3. *Inner dielectric insulator*
4. *Copper core*



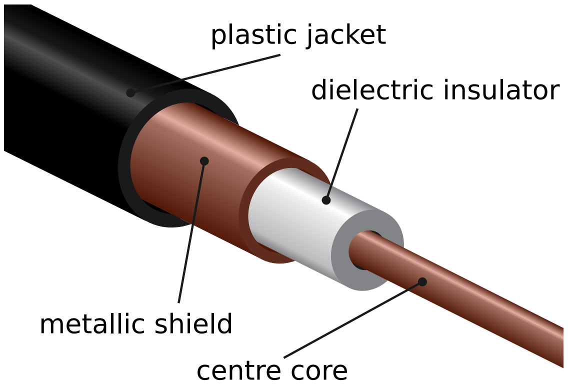
Electronic symbol for a coaxial cable

2.1 Applications

Coaxial cable is used as a transmission line for radio frequency signals. Its applications include feedlines connecting radio transmitters and receivers with their antennas, computer network (Internet) connections, and distributing cable television signals. One advantage of coaxial over other types of radio transmission line is that in an ideal coaxial cable the electromagnetic field carrying the signal exists only in the space between the inner and outer conductors. This allows coaxial cable runs to be installed next to metal objects such as gutters without the power losses that occur in other types of transmission lines. Coaxial cable also provides protection of the signal from external electromagnetic interference.

2.2 Description

Coaxial cable conducts electrical signal using an inner conductor (usually a solid copper, stranded copper or copper plated steel wire) surrounded by an insulating



Coaxial cable cutaway (not to scale)

layer and all enclosed by a shield, typically one to four layers of woven metallic braid and metallic tape. The cable is protected by an outer insulating jacket. Normally, the shield is kept at ground potential and a voltage is applied to the center conductor to carry electrical signals. The advantage of coaxial design is that electric and magnetic fields are confined to the dielectric with little leakage outside the shield. Conversely, electric and magnetic fields outside the cable are largely kept from causing interference to signals inside the cable. Larger diameter cables and cables with multiple shields have less leakage. This property makes coaxial cable a good choice for carrying weak signals that cannot tolerate interference from the environment or for higher electrical signals that must not be allowed to radiate or couple into adjacent structures or circuits.[2]

Common applications of coaxial cable include video and CATV distribution, RF and microwave transmission, and computer and instrumentation data connections.[3]

The characteristic impedance of the cable (Z_0) is determined by the dielectric constant of the inner insulator and the radii of the inner and outer conductors. A controlled cable characteristic impedance is important because the source and load impedance should be matched to ensure maximum power transfer and minimum standing wave ratio. Other important properties of coaxial cable include attenuation as a function of frequency, voltage handling capability, and shield quality.[2]

2.3 Construction

Coaxial cable design choices affect physical size, frequency performance, attenuation, power handling capabilities, flexibility, strength, and cost. The inner conductor might be solid or stranded; stranded is more flexible. To get better high-frequency performance, the inner conductor may be silver-plated. Copper-plated steel wire is often used as an inner conductor for cable used in the cable TV industry.[4]

The insulator surrounding the inner conductor may be solid plastic, a foam plastic, or air with spacers supporting the inner wire. The properties of dielectric control some electrical properties of the cable. A common choice is a solid polyethylene (PE) insulator, used in lower-loss cables. Solid Teflon (PTFE) is also used as an insulator. Some coaxial lines use air (or some other gas) and have spacers to keep the inner conductor from touching the shield.

Many conventional coaxial cables use braided copper wire forming the shield. This allows the cable to be flexible, but it also means there are gaps in the shield layer, and the inner dimension of the shield varies slightly because the braid cannot be flat. Sometimes the braid is silver-plated. For better shield performance, some cables have a double-layer shield.[4] The shield might be just two braids, but it is more common now to have a thin foil shield covered by a wire braid. Some cables may invest in more than two shield layers, such as “quad-shield”, which uses four alternating layers of foil and braid. Other shield designs sacrifice flexibility for better performance; some shields are a solid metal tube. Those cables cannot be bent sharply, as the shield will kink, causing losses in the cable.

For high-power radio-frequency transmission up to about 1 GHz, coaxial cable with a solid copper outer conductor is available in sizes of 0.25 inch upward. The outer conductor is rippled like a bellows to permit flexibility and the inner conductor is held in position by a plastic spiral to approximate an air dielectric.[4]

Coaxial cables require an internal structure of an insulating (dielectric) material to maintain the spacing between the center conductor and shield. The dielectric losses increase in this order: Ideal dielectric (no loss), vacuum, air, polytetrafluoroethylene (PTFE), polyethylene foam, and solid polyethylene. A low relative permittivity allows for higher-frequency usage. An inhomogeneous dielectric needs to be compensated by a non-circular conductor to avoid current hot-spots.

While many cables have a solid dielectric, many others have a foam dielectric that contains as much air or other gas as possible to reduce the losses by allowing the use of a larger diameter center conductor. Foam coax will have about 15% less attenuation but some types of foam dielectric can absorb moisture—especially at its many surfaces — in humid environments, significantly increasing the loss. Supports shaped like stars or spokes are even better but more expensive and very susceptible to moisture infiltration. Still more expensive were the air-spaced coaxials used for some inter-city communications in the mid-20th century. The center conductor was suspended by polyethylene discs every few centimeters. In some low-loss coaxial cables such as the RG-62 type, the inner conductor is supported by a spiral strand of polyethylene, so that an air space exists between most of the conductor and the inside of the jacket. The lower dielectric constant of air allows for a greater inner diameter at the same impedance and a greater outer diameter at the same cutoff frequency, lowering ohmic losses. Inner conductors are sometimes silver-plated to smooth the surface and reduce losses due to skin effect.[4] A rough surface prolongs the path for the current and concentrates the current at peaks and, thus, increases ohmic losses.

The insulating jacket can be made from many materials. A common choice is PVC, but some applications may require fire-resistant materials. Outdoor applications may require the jacket resist ultraviolet light, oxidation and rodent damage. Flooded coaxial cables use a water blocking gel to protect the cable from water infiltration through minor cuts in the jacket. For internal chassis connections the insulating jacket may be omitted.

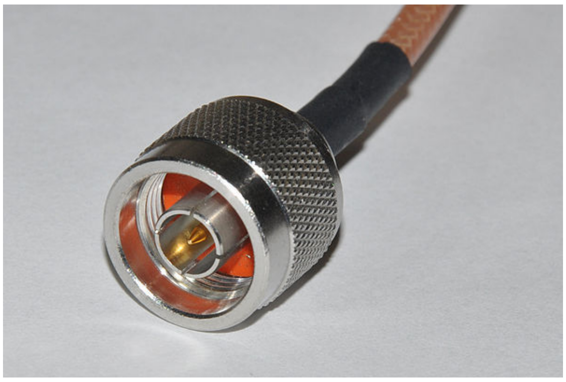
2.4 Signal propagation

Twin-lead transmission lines have the property that the electromagnetic wave propagating down the line extends into the space surrounding the parallel wires. These lines have low loss, but also have undesirable characteristics. They cannot be bent, tightly twisted, or otherwise shaped without changing their characteristic impedance, causing reflection of the signal back toward the source. They also cannot be buried or run along or attached to anything conductive, as the extended fields will induce currents in the nearby conductors causing unwanted radiation and detuning of the line. Coaxial lines largely solve this problem by confining virtually all of the electromagnetic wave to the area inside the cable. Coaxial lines can therefore be bent and moderately twisted without negative effects, and they can be strapped to conductive supports without inducing unwanted currents in them.

In radio-frequency applications up to a few gigahertz, the wave propagates primarily in the transverse electric magnetic (TEM) mode, which means that the electric and magnetic fields are both perpendicular to the direction of propagation. However, above a certain cutoff frequency, transverse electric (TE) or transverse magnetic (TM) modes can also propagate, as they do in a waveguide. It is usually undesirable to transmit signals above the cutoff frequency, since it may cause multiple modes with different phase velocities to propagate, interfering with each other. The outer diameter is roughly inversely proportional to the cutoff frequency. A propagating surface-wave mode that does not involve or require the outer shield but only a single central conductor also exists in coax but this mode is effectively suppressed in coax of conventional geometry and common impedance. Electric field lines for this [TM] mode have a longitudinal component and require line lengths of a half-wavelength or longer.

Coaxial cable may be viewed as a type of waveguide. Power is transmitted through the radial electric field and the circumferential magnetic field in the TEM00 transverse mode. This is the dominant mode from zero frequency (DC) to an upper limit determined by the electrical dimensions of the cable.[5]

2.5 Connectors



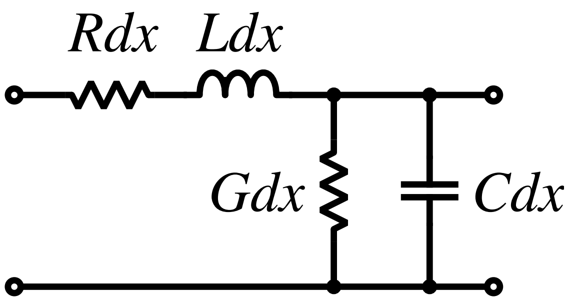
A coaxial connector (male N-type).

Main article: RF connector

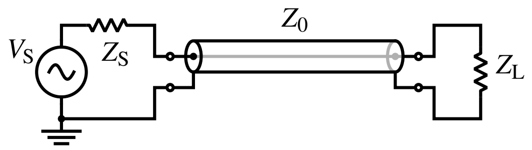
The ends of coaxial cables usually terminate with connectors. Coaxial connectors are designed to maintain a coaxial form across the connection and have the same impedance as the attached cable.[4] Connectors are usually plated with high-conductivity metals such as silver or tarnish-resistant gold. Due to the skin effect, the RF signal is only carried by the plating at higher frequencies and does not penetrate to the connector body. Silver however tarnishes quickly and the silver sulfide that is produced is poorly conductive, degrading connector performance, making silver a poor choice for this application.

2.6 Important parameters

Coaxial cable is a particular kind of transmission line, so the circuit models developed for general transmission lines are appropriate. See Telegrapher's equation.



Schematic representation of the elementary components of a transmission line.



Schematic representation of a coaxial transmission line, showing the characteristic impedance Z_0 .

2.6.1 Physical parameters

In the following section, these symbols are used:

- Length of the cable, h .
- Outside diameter of *inner* conductor, d .
- Inside diameter of the shield, D .
- Dielectric constant of the insulator, ϵ . The dielectric constant is often quoted as the relative dielectric constant ϵ_r referred to the dielectric constant of free space ϵ_0 : $\epsilon = \epsilon_r \epsilon_0$. When the insulator is a mixture of different dielectric materials (e.g., polyethylene foam is a mixture of polyethylene and air), then the term effective dielectric constant ϵ_{eff} is often used.
- Magnetic permeability of the insulator, μ . Permeability is often quoted as the relative permeability μ_r referred to the permeability of free space μ_0 : $\mu = \mu_r \mu_0$. The relative permeability will almost always be 1.

2.6.2 Fundamental electrical parameters

- Shunt capacitance per unit length, in farads per metre.[6]

$$\left(\frac{C}{h}\right) = \frac{2\pi\epsilon}{\ln(D/d)} = \frac{2\pi\epsilon_0\epsilon_r}{\ln(D/d)}$$

- Series inductance per unit length, in henrys per metre.

$$\left(\frac{L}{h}\right) = \frac{\mu}{2\pi}\ln(D/d) = \frac{\mu_0\mu_r}{2\pi}\ln(D/d)$$

- Series resistance per unit length, in ohms per metre. The resistance per unit length is just the resistance of inner conductor and the shield at low frequencies. At higher frequencies, skin effect increases the effective resistance by confining the conduction to a thin layer of each conductor.
- Shunt conductance per unit length, in siemens per metre. The shunt conductance is usually very small because insulators with good dielectric properties are used (a very low loss tangent). At high frequencies, a dielectric can have a significant resistive loss.

2.6.3 Derived electrical parameters

- Characteristic impedance in ohms (Ω). Neglecting resistance per unit length for most coaxial cables, the characteristic impedance is determined from the capacitance per unit length (C) and the inductance per unit length (L). The simplified expression is ($Z_0 = \sqrt{L/C}$). Those parameters are determined from the ratio of the inner (d) and outer (D) diameters and the dielectric constant (ϵ). The characteristic impedance is given by[7]

$$Z_0 = \frac{1}{2\pi}\sqrt{\frac{\mu}{\epsilon}}\ln\frac{D}{d} \approx \frac{60\Omega}{\sqrt{\epsilon_r}}\ln\frac{D}{d} \approx \frac{138\Omega}{\sqrt{\epsilon_r}}\log_{10}\frac{D}{d}$$

Assuming the dielectric properties of the material inside the cable do not vary appreciably over the operating range of the cable, this impedance is frequency independent above about five times the shield cutoff frequency. For typical coaxial cables, the shield cutoff frequency is 600 (RG-6A) to 2,000 Hz (RG-58C).[8]

- Attenuation (loss) per unit length, in decibels per meter. This is dependent on the loss in the dielectric material filling the cable, and resistive losses in the center conductor and outer shield. These losses are frequency dependent, the losses becoming higher as the frequency increases. Skin effect losses in the conductors can be reduced by increasing the diameter of the cable. A cable with twice the diameter will have half the skin effect resistance. Ignoring dielectric and other losses, the larger cable would halve the dB/meter loss. In designing a system, engineers consider not only the loss in the cable but also the loss in the connectors.
- Velocity of propagation, in meters per second. The velocity of propagation depends on the dielectric constant and permeability (which is usually 1).

$$v = \frac{1}{\sqrt{\epsilon\mu}} = \frac{c}{\sqrt{\epsilon_r\mu_r}}$$

- Single-mode band. In coaxial cable, the dominant mode (the mode with the lowest cutoff frequency) is the TEM mode, which has a cutoff frequency of zero; it propagates all the way down to d.c. The mode with the next lowest cutoff is the TE_{11} mode. This mode has one 'wave' (two reversals of polarity) in going around the circumference of the cable. To a good approximation, the condition for the TE_{11} mode to propagate is that the wavelength in the dielectric is no longer than the average circumference of the insulator; that is that the frequency is at least

$$f_c \approx \frac{1}{\pi(\frac{D+d}{2})\sqrt{\mu\epsilon}} = \frac{c}{\pi(\frac{D+d}{2})\sqrt{\mu_r\epsilon_r}}$$

Hence, the cable is single-mode from to d.c. up to this frequency, and might in practice be used up to 90%[9] of this frequency.

- Peak Voltage. The peak voltage is set by the breakdown voltage of the insulator. One website[10] gives:

  $$V_p = 1150\, S_{\text{mils}}\, d_{\text{in}}\, \log_{10}\left(\frac{D}{d}\right)$$

  where
  S_{mils} is the insulator's breakdown voltage in volts per mil
  d_{in} is the inner diameter in inches
  The 1150 factor converts inches (diameter) to mils (radius) and $\log_{10}$ to ln.

  The above expression may be rewritten[11] as

  $$V_p = 0.5\, S\, d\, \ln\left(\frac{D}{d}\right)$$

  where
  S is the insulator's breakdown voltage in volts per meter
  d is the inner diameter in meters

  The calculated peak voltage is often reduced by a safety factor.

2.6.4 Choice of impedance

The best coaxial cable impedances in high-power, high-voltage, and low-attenuation applications were experimentally determined at Bell Laboratories in 1929 to be 30, 60, and 77 Ω, respectively. For a coaxial cable with air dielectric and a shield of a given inner diameter, the attenuation is minimized by choosing the diameter of the inner conductor to give a characteristic impedance of 76.7 Ω.[12] When more common dielectrics are considered, the best-loss impedance drops down to a value between 52–64 Ω. Maximum power handling is achieved at 30 Ω.[13]

The approximate impedance required to match a centre-fed dipole antenna in free space (i.e., a dipole without ground reflections) is 73 Ω, so 75 Ω coax was commonly used for connecting shortwave antennas to receivers. These typically involve such low levels of RF power that power-handling and high-voltage breakdown characteristics are unimportant when compared to attenuation. Likewise with CATV, although many broadcast TV installations and CATV headends use 300 Ω folded dipole antennas to receive off-the-air signals, 75 Ω coax makes a convenient 4:1 balun transformer for these as well as possessing low attenuation.

The arithmetic mean between 30 Ω and 77 Ω is 53.5 Ω; the geometric mean is 48 Ω. The selection of 50 Ω as a compromise between power-handling capability and attenuation is in general cited as the reason for the number.[14] 50 Ω also works out tolerably well because it corresponds approximately to the drive impedance (ideally 36 ohms) of a quarter-wave monopole, mounted on a less than optimum ground plane such as a vehicle roof. The match is better at low frequencies, such as for CB Radio around 27MHz, where the roof dimensions are much less than a quarter wavelength, and relatively poor at higher frequencies, VHF and UHF, where the roof dimensions may be several wavelengths. The match is at best poor, because the antenna drive impedance, due to the imperfect ground plane, is reactive rather than purely resistive, and so a 36 ohm coaxial cable would not match properly either. Installations which need exact matching will use some kind of matching circuit at the base of the antenna, or elsewhere, in conjunction with a carefully chosen (in terms of wavelength) length of coaxial, such that a proper match is achieved, which will be only over a fairly narrow frequency range.

RG-62 is a 93 Ω coaxial cable originally used in mainframe computer networks in the 1970s and early 1980s (it was the cable used to connect IBM 3270 terminals to IBM 3274/3174 terminal cluster controllers). Later, some manufacturers of LAN equipment, such as Datapoint for ARCNET, adopted RG-62 as their coaxial cable standard. The cable has the lowest capacitance per unit-length when compared to other coaxial cables of similar size. Capacitance is the enemy of square-wave data transmission (in particular, it slows down edge transitions), and this is a much more important factor for baseband digital data transmission than power handling or attenuation.

All of the components of a coaxial system should have the same impedance to avoid internal reflections at connections between components. Such reflections may cause signal attenuation and ghosting TV picture display; multiple reflections may cause the original signal to be followed by more than one echo. In analog video or TV systems, this causes ghosting in the image. Reflections also introduce standing waves, which cause increased losses and can even result in cable dielectric breakdown with high-power transmission (see Impedance matching). Briefly, if a coaxial cable is open, the termination has nearly infinite resistance, this causes reflections; if the coaxial cable is short-circuited, the termination resistance is nearly zero, there will be reflections with the opposite polarity. Reflection will be nearly eliminated if the coaxial cable is terminated in a pure resistance equal its impedance.

2.7 Issues

2.7.1 Signal leakage

Signal leakage is the passage of electromagnetic fields through the shield of a cable and occurs in both directions. Ingress is the passage of an outside signal into the cable and can result in noise and disruption of the desired signal. Egress is the passage of signal intended to remain within the cable into the outside world and can result in a weaker signal at the end of the cable and radio frequency interference to nearby devices. Severe leakage usually results from improperly installed connectors or faults in the cable shield.

For example, in the United States, signal leakage from cable television systems is regulated by the FCC, since cable signals use the same frequencies as aeronautical and radionavigation bands. CATV operators may also choose to monitor their networks for leakage to prevent ingress. Outside signals entering the cable can cause unwanted noise and picture ghosting. Excessive noise can overwhelm the signal, making it useless.

An ideal shield would be a perfect conductor with no holes, gaps, or bumps connected to a perfect ground. However, a smooth solid highly conductive shield would be heavy, inflexible, and expensive. Such coax is used for straight line feeds to commercial radio broadcast towers. More economical cables must make compromises between shield efficacy, flexibility, and cost, such as the corrugated surface of flexible hardline, flexible braid, or foil shields. Since shields cannot be perfect conductors, current flowing on the inside of the shield produces an electromagnetic field on the outer surface of the shield.

Consider the skin effect. The magnitude of an alternating current in a conductor decays exponentially with distance beneath the surface, with the depth of penetration being proportional to the square root of the resistivity. This means that, in a shield of finite thickness, some small amount of current will still be flowing on the opposite surface of the conductor. With a perfect conductor (i.e., zero resistivity), all of the current would flow at the surface, with no penetration into and through the conductor. Real cables have a shield made of an imperfect, although usually very good, conductor, so there must always be some leakage.

The gaps or holes, allow some of the electromagnetic field to penetrate to the other side. For example, braided shields have many small gaps. The gaps are smaller when using a foil (solid metal) shield, but there is still a seam running the length of the cable. Foil becomes increasingly rigid with increasing thickness, so a thin foil layer is often surrounded by a layer of braided metal, which offers greater flexibility for a given cross-section.

Signal leakage can be severe if there is poor contact at the interface to connectors at either end of the cable or if there is a break in the shield.

To greatly reduce signal leakage into or out of the cable, by a factor of 1000, or even 10,000, superscreened cables [15] are often used in critical applications, such as for neutron flux counters in nuclear reactors.

2.7.2 Ground loops

A continuous current, even if small, along the imperfect shield of a coaxial cable can cause visible or audible interference. In CATV systems distributing analog signals the potential difference between the coaxial network and the electrical grounding system of a house can cause a visible “hum bar” in the picture. This appears as a wide horizontal distortion bar in the picture that scrolls slowly upward. Such differences in potential can be reduced by proper bonding to a common ground at the house. See ground loop.

2.7.3 Noise

External fields create a voltage across the inductance of the outside of the outer conductor between sender and receiver. The effect is less when there are several parallel cables, as this reduces the inductance and, therefore, the voltage. Because the outer conductor carries the reference potential for the signal on the inner conductor, the receiving circuit measures the wrong voltage.

Transformer effect

The transformer effect is sometimes used to mitigate the effect of currents induced in the shield. The inner and outer conductors form the primary and secondary winding of the transformer, and the effect is enhanced in some high-quality cables that have an outer layer of mu-metal. Because of this 1:1 transformer, the aforementioned voltage across the outer conductor is transformed onto the inner conductor so that the two voltages can be cancelled by the receiver. Many sender and receivers have means to reduce the leakage even further. They increase the transformer effect by passing the whole cable through a ferrite core one or more times.

2.7.4 Common mode current and radiation

Common mode current occurs when stray currents in the shield flow in the same direction as the current in the center conductor, causing the coax to radiate.

Most of the shield effect in coax results from opposing currents in the center conductor and shield creating opposite magnetic fields that cancel, and thus do not radiate. The same effect helps ladder line. However, ladder line is extremely sensitive to surrounding metal objects, which can enter the fields before they completely cancel. Coax does not have this problem, since the field is enclosed in the shield. However, it is still possible for a field to form between the shield and other connected objects, such as the antenna the coax feeds. The current formed by the field between the antenna and the coax shield would flow in the same direction as the current in the center conductor, and thus not be canceled. Energy would radiate from the coax itself, affecting the radiation pattern of the antenna. With sufficient power this could be a hazard to people near the cable. A properly placed and properly sized balun can prevent common mode radiation in coax. An isolating transformer or blocking capacitor can be used to couple a coaxial cable to equipment, where it is desirable to pass radio-frequency signals but to block direct current or low-frequency power.

2.8 Standards

Most coaxial cables have a characteristic impedance of either 50, 52, 75, or 93 Ω. The RF industry uses standard type-names for coaxial cables. Thanks to television, RG-6 is the most commonly used coaxial cable for home use, and the majority of connections outside Europe are by F connectors.

A series of standard types of coaxial cable were specified for military uses, in the form “RG-#" or “RG-#/U”. They date from World War II and were listed in *MIL-HDBK-216* published in 1962. These designations are now obsolete. The RG designation stands for Radio Guide; the U designation stands for Universal. The current military standard is MIL-SPEC MIL-C-17. MIL-C-17 numbers, such as “M17/75-RG214”, are given for military cables and manufacturer’s catalog numbers for civilian applications. However, the RG-series designations were so common for generations that they are still used, although critical users should be aware that since the handbook is withdrawn there is no standard to guarantee the electrical and physical characteristics of a cable described as “RG-# type”. The RG designators are mostly used to identify compatible connectors that fit the inner conductor, dielectric, and jacket dimensions of the old RG-series cables.

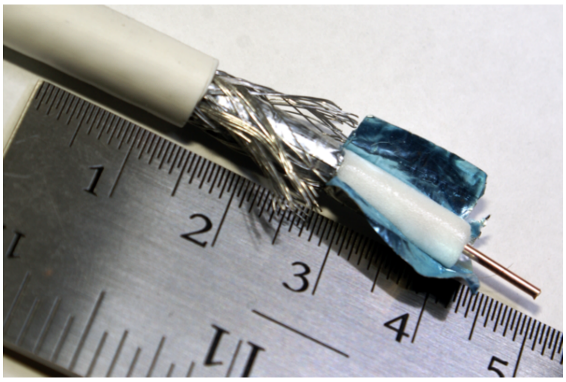
Dielectric Material Codes

- FPE is foamed polyethylene
- PE is solid polyethylene
- PF is polyethylene foam
- PTFE is polytetrafluoroethylene;
- ASP is air space polyethylene[34]

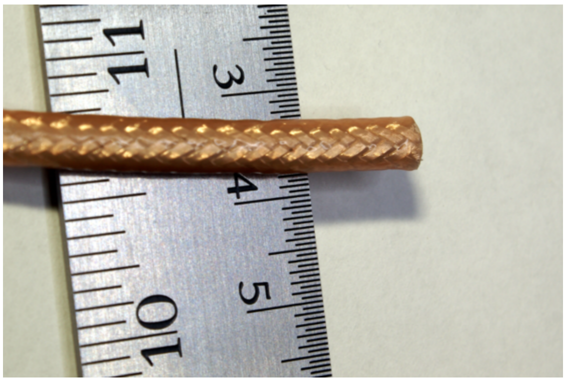
VF is the Velocity Factor; it is determined by the effective ϵ_r and μ_r [35]

- VF for solid PE is about 0.66
- VF for foam PE is about 0.78 to 0.88
- VF for air is about 1.00
- VF for solid PTFE is about 0.70
- VF for foam PTFE is about 0.84

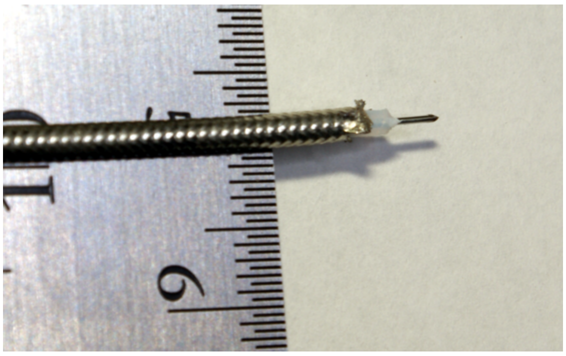
There are also other designation schemes for coaxial cables such as the URM, CT, BT, RA, PSF and WF series.



RG-6 Coaxial cable



RG-142 Coaxial cable



RG-405 semi-rigid coaxial cable

2.9 Uses

Short coaxial cables are commonly used to connect home video equipment, in ham radio setups, and in measurement electronics. They used to be common for implementing computer networks, in particular Ethernet, but twisted pair cables have replaced them in most applications except in the growing consumer cable modem market for broadband Internet access.

Long distance coaxial cable was used in the 20th century to connect radio networks, television networks, and Long Distance telephone networks though this has largely been superseded by later methods (fibre optics, T1/E1, satellite).

Shorter coaxials still carry cable television signals to the majority of television receivers, and this purpose consumes the majority of coaxial cable production. In 1980s and early 1990s coaxial cable was also used in computer networking, most prominently in Ethernet networks, where it was later in late 1990s to early 2000s replaced by UTP cables in North America and STP cables in Western Europe, both with 8P8C modular connectors.

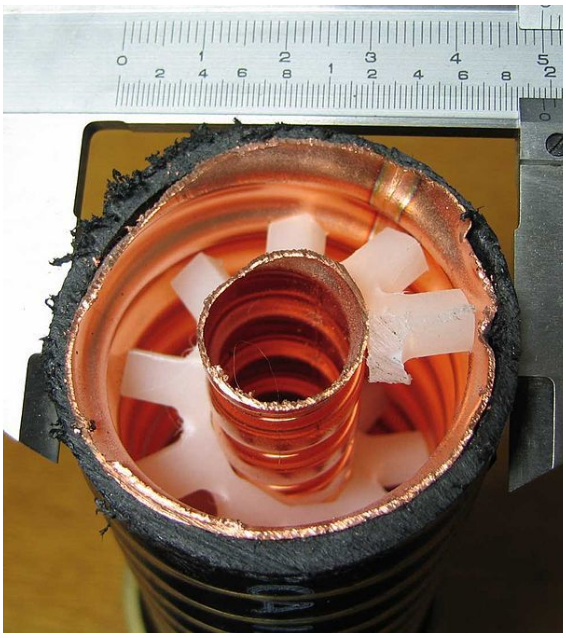
Micro coaxial cables are used in a range of consumer devices, military equipment, and also in ultra-sound scanning equipment.

The most common impedances that are widely used are 50 or 52 ohms, and 75 ohms, although other impedances are available for specific applications. The 50 / 52 ohm cables are widely used for industrial and commercial two-way radio frequency applications (including radio, and telecommunications), although 75 ohms is commonly used for broadcast television and radio.

Coax cable is often used to carry data/signals from an antenna to a receiver—from a satellite dish to a satellite receiver, from a television antenna to a television receiver, from a radio mast to a radio receiver, etc. In many cases, the same single coax cable carries power in the opposite direction, to the antenna, to power the low-noise amplifier. In some cases a single coax cable carries (unidirectional) power and bidirectional data/signals, as in DiSEqC.

2.10 Types

2.10.1 Hard line



1-5/8" flexible line

Hard line is used in broadcasting as well as many other forms of radio communication. It is a coaxial cable constructed using round copper, silver or gold tubing or a combination of such metals as a shield. Some lower-quality hard line may use aluminum shielding, aluminum however is easily oxidized and unlike silver or gold oxide, aluminum oxide drastically loses effective conductivity. Therefore all connections must be air and water tight. The center conductor may consist of solid copper, or copper-plated aluminum. Since skin effect is an issue with RF, copper plating provides sufficient surface for an effective conductor. Most varieties of hardline used for external chassis or when exposed to the elements have a PVC jacket; however, some internal applications may omit the insulation jacket. Hard line can be very thick, typically at least a half inch or 13 mm and up to several times that, and has low loss even at high power. These large-scale hard lines are almost always used in the connection between a transmitter on the ground and the antenna or aerial on a tower. Hard line may also be known by trademarked names such as Heliax (Andrew),[36] or Cablewave (RFS/Cablewave).[37] Larger varieties of hardline may have a center conductor that is constructed from either rigid or corrugated copper tubing. The dielectric in hard line may consist of polyethylene foam, air, or a pressurized gas such as nitrogen or desiccated air (dried air). In gas-charged lines, hard plastics such as nylon are used as spacers to separate the inner and outer conductors. The addition of these gases into the dielectric space reduces moisture contamination, provides a stable dielectric constant, and provides a reduced risk of internal arcing. Gas-filled hardlines are usually used on high-power RF transmitters such as television or radio broadcasting, military transmitters, and high-power amateur radio applications but may also be used on some critical lower-power applications such as those in the microwave bands. However, in the microwave region, *waveguide* is more often used than hard line for transmitter-to-antenna, or antenna-to-receiver applications. The various shields used in hardline also differ; some forms use rigid tubing, or pipe, others may use a corrugated tubing, which makes bending easier, as well as reduces kinking when the cable is bent to conform. Smaller varieties of hard line may be used internally in some high-frequency applications, in particular in equipment within the microwave range, to reduce interference between stages of the device.

2.10.2 Radiating

Main article: Leaky feeder

Radiating or **leaky cable** is another form of coaxial cable which is constructed in a similar fashion to hard line, however it is constructed with tuned slots cut into the shield. These slots are tuned to the specific RF wavelength of operation or tuned to a specific radio frequency band. This type of cable is to provide a tuned bi-directional “desired” leakage effect between transmitter and receiver. It is often used in elevator shafts, US Navy Ships, underground transportation tunnels and in other areas where an antenna is not feasible. One example of this type of cable is Radiax (Andrew).[38]

2.10.3 RG-6

Main article: RG-6

RG-6 is available in four different types designed for various applications. In addition, the core may be copper clad steel (CCS) or bare solid copper (BC). “Plain” or “house” RG-6 is designed for indoor or external house wiring. “Flooded” cable is infused with waterblocking gel for use in underground conduit or direct burial. “Messenger” may contain some waterproofing but is distinguished by the addition of a steel messenger wire along its length to carry the tension involved in an aerial drop from a utility pole. "Plenum" cabling is expensive and comes with a special Teflon-based outer jacket designed for use in ventilation ducts to meet fire codes. It was developed since the plastics used as the outer jacket and inner insulation in many “Plain” or “house” cabling gives off poison gas when burned.

2.10.4 Triaxial cable

Main article: Triaxial cable

Triaxial cable or **triax** is coaxial cable with a third layer of shielding, insulation and sheathing. The outer shield, which is earthed (grounded), protects the inner shield from electromagnetic interference from outside sources.

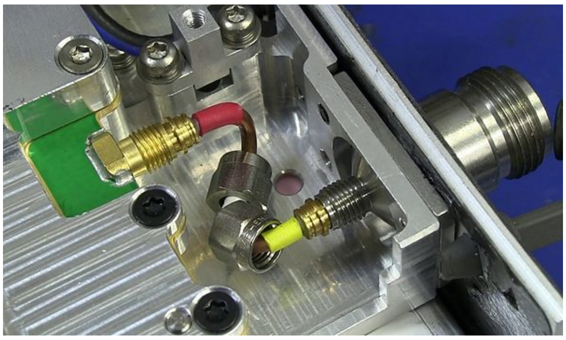
2.10.5 Twin-axial cable

Main article: Twinaxial cabling

Twin-axial cable or **twinax** is a balanced, twisted pair within a cylindrical shield. It allows a nearly perfect differential signal which is *both* shielded *and* balanced to pass through. Multi-conductor coaxial cable is also sometimes used.

2.10.6 Semi-rigid

Semi-Rigid coax assembly



Semi-Rigid coax installed in an Agilent N9344C 20GHz spectrum analyser

Semi-rigid cable is a coaxial form using a solid copper outer sheath. This type of coax offers superior screening compared to cables with a braided outer conductor, especially at higher frequencies. The major disadvantage is that the cable, as its name implies, is not very flexible, and is not intended to be flexed after initial forming. (See “hard line”)

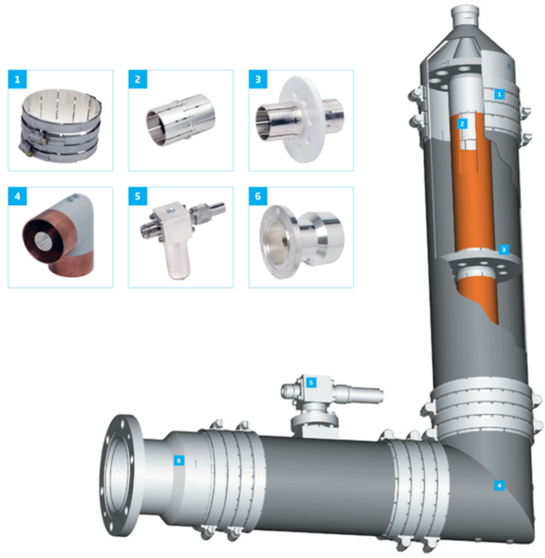
Conformable cable is a flexible reformable alternative to semi-rigid coaxial cable used where flexibility is required. Conformable cable can be stripped and formed by hand without the need for specialized tools, similar to standard coaxial cable.

2.10.7 Rigid line

Rigid line

Rigid line is a coaxial line formed by two copper tubes maintained concentric every other meter using PTFE-supports. Rigid lines can not be bent, so they often need elbows. Interconnection with rigid line is done with an inner bullet/inner support and a flange or connection kit. Typically rigid lines are connected using standardised EIA RF Connectors whose bullet and flange sizes match the standard line diameters, for each outer diameter either 75 or 50ohm inner tubes can be obtained. Rigid line is commonly used indoors for interconnection between high power transmitters and other RF-components, but more rugged rigid line with weatherproof flanges is used outdoors on antenna masts, etc. In the interests of saving weight and costs, on masts and similar structures the outer line is often aluminium, and special care must be taken to prevent corrosion. With a flange connector it is also possible to go from rigid line to hard line. Many broadcasting antennas and antenna splitters use the flanged rigid line interface even when connecting to flexible coaxial cables and hard line.

Rigid line is produced in a number of different sizes:



Rigid line parts

2.10.8 Cables used in the UK

At the start of analogue satellite TV broadcasts in the UK by BskyB, a 75 ohm cable referred to as *RG6* was used. This cable had a 1 mm copper core, air-spaced polyethylene dielectric and copper braid on an aluminium foil shield. When installed outdoors without protection, the cable was affected by UV radiation, which cracked the PVC outer sheath and allowed moisture ingress. The combination of copper, aluminium, moisture and air caused rapid corrosion, sometimes resulting in a 'snake swallowed an egg' appearance. Consequently, despite the higher cost, the RG6 cable was dropped in favour of CT100 when BSKYB launched its digital broadcasts.

From around 1999 to 2005 (when CT100 manufacturer Raydex went out of business), CT100 remained the 75 ohm cable of choice for satellite TV and especially BskyB. It had an air-spaced polyethylene dielectric, a 1 mm solid copper core and copper braid on copper foil shield. CT63 was a thinner cable in 'shotgun' style, meaning that it was two cables moulded together and was used mainly by BskyB for the twin connection required by the *Sky+* satellite TV receiver, which incorporated a hard drive recording system and a second, independent tuner.

In 2005, these cables were replaced by WF100 and WF65, respectively, manufactured by Webro and having a similar construction but a foam dielectric that provided the same electrical performance as air-spaced but was more robust and less likely to be crushed.

At the same time, with the price of copper steadily rising, the original RG6 was dropped in favour of a construction that used a copper-clad steel core and aluminium braid on aluminium foil. Its lower price made it attractive to aerial installers looking for a replacement for the so-called *low-loss* cable traditionally used for UK terrestrial aerial installations. This cable had been manufactured with a decreasing number of strands of braid, as the price of copper increased, such that the shielding performance of cheaper brands had fallen to as low as 40 percent. With the advent of digital terrestrial transmissions in the UK, this low-loss cable was no longer suitable.

The new RG6 still performed well at high frequencies because of the skin effect in the copper cladding. However, the aluminium shield had a high DC resistance and the steel core an even higher one. The result is that this type of cable could not reliably be used in satellite TV installations, where it was required to carry a significant amount of current, because the voltage drop affected the operation of the low noise block downconverter (LNB) on the dish.

A problem with all the aforementioned cables, when passing current, is that electrolytic corrosion can occur in the connections unless moisture and air are excluded. Consequently, various solutions to exclude moisture have been proposed. The first was to seal the connection by wrapping it with self-amalgamating rubberised tape, which bonds to itself when activated by stretching. The second proposal, by the American Channel Master company (now owned by Andrews corp.) at least as early as 1999, was to apply silicone grease to the wires making connection. The third proposal was to fit a self-sealing plug to the cable. All of these methods are reasonably successful if implemented correctly.

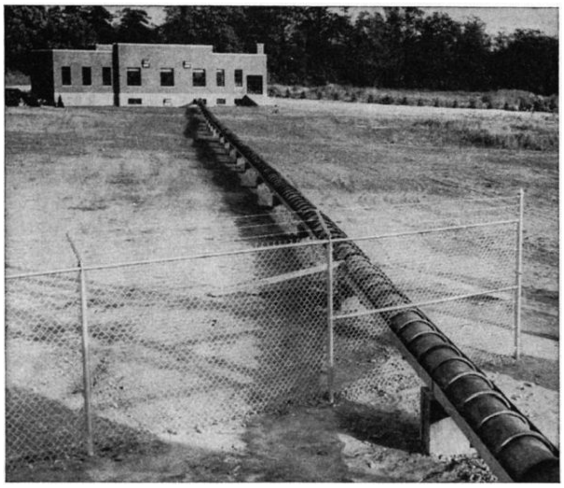
2.11 Interference and troubleshooting

Coaxial cable insulation may degrade, requiring replacement of the cable, especially if it has been exposed to the elements on a continuous basis. The shield is normally grounded, and if even a single thread of the braid or filament of foil touches the center conductor, the signal will be shorted causing significant or total signal loss. This most often occurs at improperly installed end connectors and splices. Also, the connector or splice must be properly attached to the shield, as this provides the path to ground for the interfering signal.

Despite being shielded, interference can occur on coaxial cable lines. Susceptibility to interference has little relationship to broad cable type designations (e.g. RG-59, RG-6) but is strongly related to the composition and configuration of the cable's shielding. For cable television, with frequencies extending well into the UHF range, a foil shield is normally provided, and will provide total coverage as well as high effectiveness against high-frequency interference. Foil shielding is ordinarily accompanied by a tinned copper or aluminum braid shield, with anywhere from 60 to 95% coverage. The braid is important to shield effectiveness because (1) it is more effective than foil at preventing low-frequency interference, (2) it provides higher conductivity to ground than foil, and (3) it makes attaching a connector easier and more reliable. "Quad-shield" cable, using two low-coverage aluminum braid shields and two layers of foil, is often used in situations involving troublesome interference, but is less effective than a single layer of foil and single high-coverage copper braid shield such as is found on broadcast-quality precision video cable.

In the United States and some other countries, cable television distribution systems use extensive networks of outdoor coaxial cable, often with in-line distribution amplifiers. Leakage of signals into and out of cable TV systems can cause interference to cable subscribers and to over-the-air radio services using the same frequencies as those of the cable system.

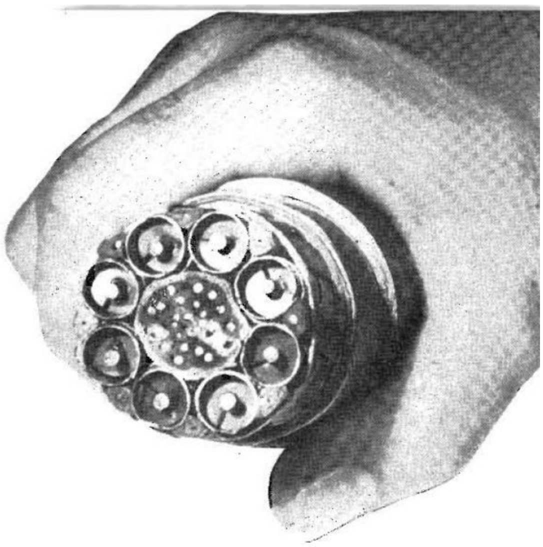
2.12 History



Early coaxial antenna feedline of 50 kW radio station WNBC, New York, in 1930s

- 1880 — Coaxial cable patented in England by Oliver Heaviside, patent no. 1,407.[39]
- 1884 — Siemens & Halske patent coaxial cable in Germany (Patent No. 28,978, 27 March 1884).[40]
- 1929 — First modern coaxial cable patented by Lloyd Espenschied and Herman Affel of AT&T's Bell Telephone Laboratories.[41]
- 1936 — First closed circuit transmission of TV pictures on coaxial cable, from the 1936 Summer Olympics in Berlin to Leipzig.[42]
- 1936 — World's first underwater coaxial cable installed between Apollo Bay, near Melbourne, Australia, and Stanley, Tasmania. The 300 km cable can carry one 8.5-kHz broadcast channel and seven telephone channels.[43]

- 1936 — AT&T installs experimental coaxial telephone and television cable between New York and Philadelphia, with automatic booster stations every ten miles. Completed in December, it can transmit 240 telephone calls simultaneously.[44][45]
- 1936 — Coaxial cable laid by the General Post Office (now BT) between London and Birmingham, providing 40 telephone channels.[46][47]
- 1941 — First commercial use in USA by AT&T, between Minneapolis, Minnesota and Stevens Point, Wisconsin. L1 system with capacity of one TV channel or 480 telephone circuits.



AT&T coaxial cable trunkline installed between East Coast and Midwest in 1949. Each of the 8 coaxial subcables could carry 480 telephone calls or one television channel.

- 1949 — On January 11, eight stations on the US East Coast and seven Midwestern stations are linked via a long-distance coaxial cable.[48]
- 1956 — First transatlantic coaxial cable laid, TAT-1.[49][50]

2.13 See also

- Transmission line
- Radio frequency power transmission
- L-carrier
- Balanced pair
- Shielded cable
- Triaxial cable
- Twinaxial cabling

2.14 References

[1] Nahin, Paul J. (2002). *Oliver Heaviside: The Life, Work, and Times of an Electrical Genius of the Victorian Age*. ISBN 0-8018-6909-9.

[2] H. Ward Silver, N0AX, and Mark J. Wilson, K1RO, ed. (2010). "Chapter 20: Transmission Lines". *The ARRL Handbook for Radio Communications* (87th ed.). The American Radio Relay League. ISBN 0-87259-144-1.

[3] Martin J. Van Der Burgt. "Coaxial Cables and Applications" (PDF). Belden. p. 4. Retrieved 11 July 2011.

[4] *The ARRL UHF/Microwave Experimenter's Manual*, American Radio Relay League, Newington CT USA,1990 ISBN 0-87259-312-6, Chapter 5 *Transmission Media* pages 5.19 through 5.21

[5] Jackson, John David (1962). *Classical Electrodynamics*. New York: John Wiley & Sons, Inc. p. 244.

[6] Pozar, David M. (1993). *Microwave Engineering* Addison-Wesley Publishing Company. ISBN 0-201-50418-9.

[7] Elmore, William C.; Heald, Mark A. (1969). *Physics of Waves*. ISBN 0-486-64926-1.

[8] Ott, Henry W. (1976). *Noise Reduction Techniques in Electronic Systems*. ISBN 0-471-65726-3.

[9] Kizer, George Maurice (1990). *Microwave communication*. Iowa State University Press. p. 312. ISBN 978-0-8138-0026-4.

[10] "Coaxial Cable Equations Formulas". RF Cafe. Retrieved 2012-01-25.

[11] See "field enhancement" discussion at http://www.microwaves101.com/encyclopedia/why50ohms.cfm

[12] "Why 50 Ohms?". Microwaves 101. 2009-01-13. Retrieved 2012-01-25.

[13] "Coax power handling". Microwaves 101. 2008-09-14. Retrieved 2012-01-25.

[14] "Why 50 Ohms?". Microwaves 101. 2009-01-13. Retrieved 2012-01-25.

[15] "Superscreened Cables".

[16] "Coaxial Cable Specifications for RG-6". madaboutcable.com.

[17] "Times Microwave Coax Loss Calculator". Retrieved 2011-10-26.

[18] http://www.dxengineering.com/pdf/Belden%20RG8X%20Date%209258.pdf

[19] "Coaxial Cable Specifications for RG-11". madaboutcable.com.

[20] "Coaxial Cable Specifications for RG-58". madaboutcable.com.

[21] "Coaxial Cable Specifications for RG-59". madaboutcable.com.

[22] "Cable Velocity Factor and Loss Data". febo.com.

[23] "Coaxial Cable Specifications for RG-62". madaboutcable.com.

[24] "Coaxial Cable Specifications for RG-178". madaboutcable.com.

[25] Caledonian.com - RG178 Mini-Coax

[26] "Coaxial Cable Specifications for 5 Core RG-179 (RGBHV)". madaboutcable.com.

[27]

[28] "Coaxial Cable Specifications for RG-213". madaboutcable.com.

[29] "Coaxial Cable Specifications for RG-214". madaboutcable.com.

[30] "Coaxial Cable Specifications for RG-316". madaboutcable.com.

[31] "Coaxial Cable Specifications for RG-400". madaboutcable.com.

[32] "Times Microwave LMR-240 Data Sheet" (PDF). Retrieved 2011-10-26.

[33] "Radio City Inc".

[34] "Coaxial Cable Specifications Cables Chart". RF Cafe. Retrieved 2012-01-25.

[35] "Phase Velocity". Microwaves 101. 2010-03-30. Retrieved 2012-01-25.

[36] "Andrew Heliax".

[37] "Cablewave Radio Frequency Systems <http://www.rfsworld.com>".

[38] "Andrew Radiax".

[39] Google Book Search - Oliver Heaviside By Paul J. Nahin

[40] Feldenkirchen, Wilfried (1994). *Werner von Siemens - Inventor and International Entrepreneur*. ISBN 0-8142-0658-1.

[41] U.S. Patent 1,835,031

[42] earlytelevision.org - Early Electronic Television - The 1936 Berlin Olympics

[43] The worldwide history of telecommunications By Anton A. Huurdeman - Copper-Line Transmission

[44] "Coaxial Debut," *Time*, Dec. 14, 1936.

[45] Boing Boing - Gallery: An illustrated history of the transoceanic cable

[46] Google books - Broadcast engineer's reference book By Edwin Paul J. Tozer

[47] Radio-electronics.com - Coaxial feeder or RF coax cable

[48] Teachout, Terry. "The New-Media Crisis of 1949". Wall Street Journal. Retrieved 19 January 2015.

[49] Atlantic-cable.com - 1956 TAT-1 Silver Commemorative Dish

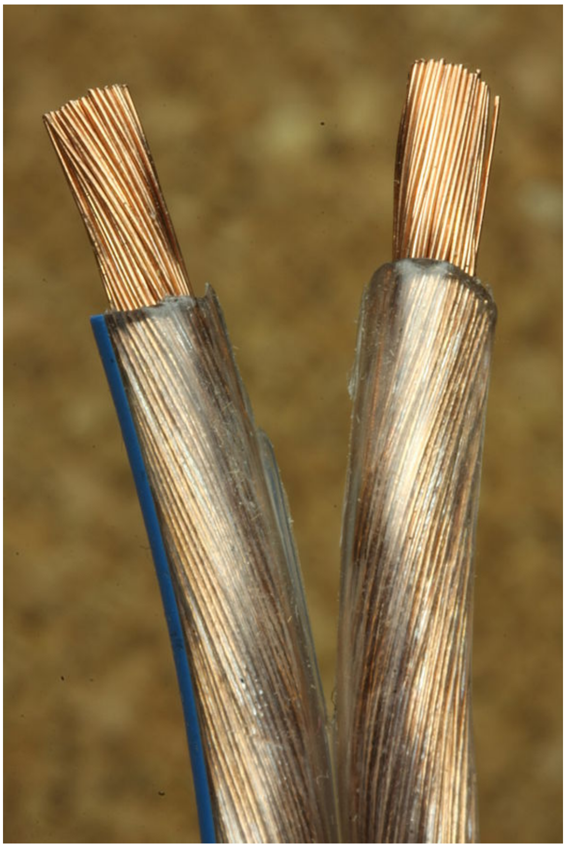
[50] Google books - The worldwide history of telecommunications By Anton A. Huurdeman

2.15 External links

- *RF transmission lines and fittings.* Military Standardization Handbook MIL-HDBK-216, U.S. Department of Defense, 4 January 1962.
- *Withdrawal Notice for MIL-HDBK-216 2001*
- *Cables, radio frequency, flexible and rigid.* Details Specification MIL-DTL-17H, 19 August 2005 (superseding MIL-C-17G, 9 March 1990).
- *Radio-frequency cables*, International Standard IEC 60096.
- *Coaxial communication cables*, International Standard IEC 61196.
- *Coaxial cables*, British Standard BS EN 50117
- H. P. Westman et al., (ed), *Reference Data for Radio Engineers, Fifth Edition*, 1968, Howard W. Sams and Co., no ISBN, Library of Congress Card No. 43-14665
- What's the Best Cable to Use (UK)

Chapter 3

Copper wire and cable



Copper wires.

Copper has been used in electric wiring since the invention of the electromagnet and the telegraph in the 1820s.[1][2] The invention of the telephone in 1876 created further demand for copper wire as an electrical conductor.[3]

Copper is the electrical conductor in many categories of electrical wiring.[3][4] Copper wire is used in power generation, power transmission, power distribution, telecommunications, electronics circuitry, and countless types of electrical equipment.[5] Copper and its alloys are also used to make electrical contacts. Electrical wiring in buildings is the most important market for the copper industry.[6] Roughly half of all copper mined is used to manufacture electrical wire and cable conductors.[5]

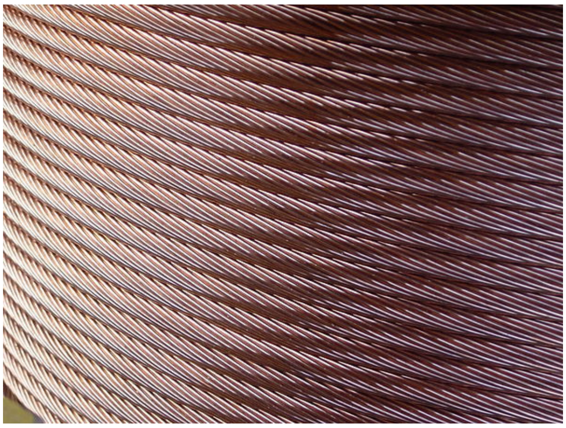
Copper cable.

Coaxial cable made from copper.

3.1 Properties of copper

3.1.1 Electrical conductivity

Electrical conductivity is a measure of how well a material transports an electric charge. This is an essential property in electrical wiring systems. Copper has the highest electrical conductivity rating of all non-precious metals: the electrical resistivity of copper = 16.78 nΩ•m at 20 °C. Specially-pure Oxygen-Free Electronic (OFE) copper is about 1% more conductive (i.e., achieves a minimum of 101% IACS).[7][8]



Copper cable.

Fine copper wire.

The theory of metals in their solid state[9] helps to explain the unusually high electrical conductivity of copper. In a copper atom, the outermost 4s energy zone, or conduction band, is only half filled, so many electrons are able to carry electric current. When an electric field is applied to a copper wire, the conduction of electrons accelerates towards the electropositive end, thereby creating a current. These electrons encounter resistance to their passage by colliding with impurity atoms, vacancies, lattice ions, and imperfections. The average distance travelled between collisions, defined as the "mean free path," is inversely proportional to the resistivity of the metal. What is unique about copper is its long mean free path (approximately 100 atomic spacings at room temperature). This mean free path increases rapidly as copper is chilled.[10]

Because of its superior conductivity, annealed copper became the international standard to which all other electrical conductors are compared. In 1913, the International Electrotechnical Commission defined the conductivity of commercially pure copper in its International Annealed Copper Standard, as 100% IACS = 58.0 MS/m at 20 °C, decreasing by 0.393%/°C.[7][8] Because commercial purity has improved over the last century, copper conductors used in building wire often slightly exceed the 100% IACS standard.[11]

The main grade of copper used for electrical applications is electrolytic-tough pitch (ETP) copper (CW004A or ASTM designation C11040). This copper is at least 99.90% pure and has an electrical conductivity of at least 101% IACS. ETP copper contains a small percentage of oxygen (0.02 to 0.04%). If high conductivity copper needs to be welded or brazed or used in a reducing atmosphere, then oxygen-free copper (CW008A or ASTM designation C10100) may be used.[12]

Several electrically conductive metals are less dense than copper, but require larger cross sections to carry the same current and may not be usable when limited space is a major requirement.[10][13]

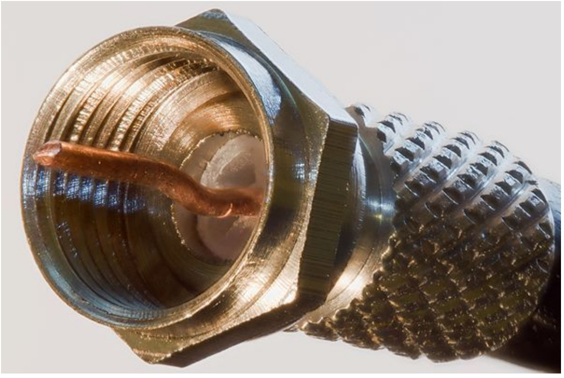
Aluminium has 61% of the conductivity of copper.[14] The cross sectional area of an aluminium conductor must be 56% larger than copper for the same current carrying capability.[15] The need to increase the thickness of aluminium wire restricts its use in several applications,[13] such as in small motors and automobiles. In some applications such as aerial electric power transmission cables, copper is rarely used.

Silver, a precious metal, is the only metal with a higher electrical conductivity than copper. The electrical conductivity of silver is 106% of that of annealed copper on the IACS scale, and the electrical resistivity of silver = 15.9 nΩ•m at 20°C.[16][17] The high cost of silver combined with its low tensile strength limits its use to special applications, such as joint plating and sliding contact surfaces, and plating for the conductors in high-quality coaxial cables used at frequencies above 30 MHz.

3.1.2 Tensile strength

Tensile strength measures the force required to pull an object such as rope, wire, or a structural beam to the point where it breaks. The tensile strength of a material is the maximum amount of tensile stress it can take before breaking.

Copper's higher tensile strength (200–250 N/mm^2 annealed) compared to aluminium (100 N/mm^2 for typical conductor alloys[18]) is another reason why copper is used extensively in the building industry. Copper's high strength resists stretching, neck-down, creep, nicks and breaks, and thereby also prevents failures and service interruptions.[19] Copper is much heavier than aluminum



F connectors attached to coaxial cables are used for TV aerial and satellite dish connections to a TV or set top box.

for conductors of equal current carrying capacity, so the high tensile strength is offset by its increased weight.

3.1.3 Ductility

Ductility is a material's ability to deform under tensile stress. This is often characterized by the material's ability to be stretched into a wire. Ductility is especially important in metalworking because materials that crack or break under stress cannot be hammered, rolled, or drawn (drawing is a process that uses tensile forces to stretch metal).

Copper has a higher ductility than alternate metal conductors with the exception of gold and silver.[20] Because of copper's high ductility, it is easy to draw down to diameters with very close tolerances.[21]

3.1.4 Strength and ductility combination

Usually, the stronger a metal is, the less pliable it is. This is not the case with copper. A unique combination of high strength and high ductility makes copper ideal for wiring systems. At junction boxes and at terminations, for example, copper can be bent, twisted, and pulled without stretching or breaking.[19]

3.1.5 Creep resistance

Creep is the gradual deformation of a material from constant expansions and contractions under "load, no-load" conditions. This process has adverse effects on electrical systems: terminations can become loose, causing connections to heat up or create dangerous arcing.

Copper has excellent creep characteristics which minimizes loosening at connections. For other metal conductors that creep, extra maintenance is required to check terminals periodically and ensure that screws remain tightened to prevent arcing and overheating.[19]

3.1.6 Corrosion resistance

Corrosion is the unwanted breakdown and weakening of a material due to chemical reactions. Copper generally resists corrosion from moisture, humidity, industrial pollution, and other atmospheric influences. However, any corrosion oxides, chlorides, and sulfides that do form on copper are somewhat conductive.[14][19]

Under many application conditions copper is higher on the galvanic series than other common structural metals, meaning that copper wire is less likely to be corroded in wet conditions. However, any more anodic metals in contact with copper will be corroded since will essentially be sacrificed to the copper.

3.1.7 Coefficient of thermal expansion

Metals and other solid materials expand upon heating and contract upon cooling. This is an undesirable occurrence in electrical systems. Copper has a low coefficient of thermal expansion for an electrical conducting material. Aluminium, an alternate common conductor, expands nearly one third more than copper under increasing temperatures. this higher degree of expansion;along with aluminium's lower ductility can cause electrical problems when bolted connections are improperly installed. By using proper hardware, such as spring pressure connections and cupped or split washers at the joint, it may be possible to create aluminium joints that compare in quality to copper joints.[14]

3.1.8 Thermal conductivity

Thermal conductivity is the ability of a material to conduct heat. In electrical systems, high thermal conductivity is important for dissipating waste heat, particularly at terminations and connections. Copper has a 60% higher thermal conductivity rating than aluminium,[19] so it is better able to reduce thermal hot spots in electrical wiring systems.[10][22]

3.1.9 Solderability

Soldering is a process whereby two or more metals are joined together by a heating process. This is a desirable property in electrical systems. Copper is readily soldered to make durable connections when necessary.

3.1.10 Ease of installation

The inherent strength, hardness, and flexibility of copper building wire make it very easy to work with. Copper wiring can be installed simply and easily with no special tools, washers, pigtails, or joint compounds. Its flexibility makes it easy to join, while its hardness helps keep connections securely in place. It has good strength for pulling wire through tight places ("pull-through"), including conduits. It can be bent or twisted easily without breaking. It can be stripped and terminated during installation or service with far less danger of nicks or breaks. And it can be connected without the use of special lugs and fittings. The combination of all of these factors makes it easy for electricians to install copper wire.[19][23]

3.2 Types of copper wire and cable

3.2.1 Solid and stranded

Further information: Wire#Forms of wire

Solid wire consists of one strand of copper metal wire,

Stranded copper lamp cord, 16 gauge

bare or surrounded by an insulator. Single-strand copper conductors are typically used as magnet wire in motors and transformers. They are relatively rigid, do not bend easily, and are typically installed in permanent, infrequently handled, and low flex applications.

Stranded wire has a group of copper wires braided or twisted together. Stranded wire is more flexible and easier to install than a large single-strand wire of the same cross section. Stranding improves wire life in applications with vibration. A particular cross-section of a stranded conductor gives it essentially the same resistance characteristics as a single-strand conductor, but with added flexibility.[24]

3.2.2 Cable

Further information: Cable

A copper cable consists of two or more copper wires running side by side and bonded, twisted or braided together to form a single assembly. Electrical cables may be made more flexible by stranding the wires.

Copper wires in a cable may be bare or they may be plated to reduce oxidation with a thin layer of another metal, most often tin but sometimes gold or silver. Plating may lengthen wire life and makes soldering easier. Twisted pair and coaxial cables are designed to inhibit electromagnetic interference, prevent radiation of signals, and to provide transmission lines with defined characteristics. Shielded cables are encased in foil or wire mesh.

3.3 Applications for copper wire and cable

Electrolytic-tough pitch (ETP) copper, a high-purity copper that contains oxygen as an alloying agent, represents the bulk of electrical conductor applications because of its high electrical conductivity and improved annealability. ETP copper is used for power transmission, power distribution, and telecommunications.[5] Common applications include building wire, motor windings, cables, and busbars. Oxygen-free coppers are used to resist hydrogen embrittlement when extensive amounts of cold work is needed, and for applications requiring higher ductility (e.g., telecommunications cable). When hydrogen embrittlement is a concern and low electrical resistivity is not required, phosphorus may be added to copper.[10]

For certain applications, copper alloy conductors are preferred instead of pure copper, especially when higher strengths or improved abrasion and corrosion resistance properties are required. However, relative to pure copper, the higher strength and corrosion resistance benefits that are offered by copper alloys are offset by their lower electrical conductivities. Design engineers weigh the advantages and disadvantages of the various types of copper and copper alloy conductors when determining which type to specify for a specific electrical application. An example of a copper alloy conductor is cadmium copper wire, which is used for railroad electrification in North America.[5] In Britain the BPO (later Post Office Telecommunications) used cadmium copper aerial lines with 1% cadmium for extra strength; for local lines 40 lb/mile (1.3 mm dia) and for toll lines 70 lb/mile (1.7 mm dia).[25]

Some of the major application markets for copper wire and cable are summarized below.

3.3.1 Building wire

Building wire distributes electric power inside residential, commercial, or industrial buildings, mobile homes,

Mineral insulated copper clad cable (pyro).

recreational vehicles, boats, and substations at voltages up to 600 V. The thickness of the wire is based on amperage requirements in conjunction with safe operating temperatures. Solid wire is used for smaller diameters; thicker diameters are stranded to provide flexibility. Conductor types include non-metallic/non-metallic corrosion-resistant cable (two or more insulated conductors with a nonmetallic outer sheath), armored or BX cable (cables are surrounded by a flexible metal enclosure), metal clad cable, service entrance cable, underground feeder cable, TC cable, fire resistant cable, and mineral insulated cable, including mineral-insulated copper-clad cable.[26] Copper is commonly used for building wire because of its conductivity, strength, and reliability. Over the life of a building wire system, copper can also be the most economical conductor.

Copper used in building wire has a conductivity rating of 100% IACS[8][27] or better. Copper building wire requires less insulation and can be installed in smaller conduits than when lower-conductivity conductors are used. Also, comparatively, more copper wire can fit in a given conduit than conductors with lower conductivities. This greater “wire fill” is a special advantage when a system is rewired or expanded.[19]

Copper building wire is compatible with brass and quality plated screws. The wire provides connections that will not corrode or creep. It is not, however, compatible with aluminium wire or connectors. If the two metals are joined, a galvanic reaction can occur. Anodic corrosion during the reaction can disintegrate the aluminium. This is why most appliance and electrical equipment manufacturers use copper lead wires for connections to building wiring systems.[23]

“All-copper” building wiring is a term that refers to homes where the inside electrical service is carried exclusively over copper wiring. In all-copper homes, copper conductors are used in circuit breaker panels, branch circuit wiring (to outlets, switches, lighting fixtures and the like), and in dedicated branches serving heavy-load appliances (such as ranges, ovens, clothes dryers and air conditioners).[28]

Power cable 5G16 (5 wires, green-yellow ground wire, 16mm^2.

Attempts to replace copper with aluminium in building wire were curtailed in most countries when it was found that aluminium connections gradually loosened due to their inherent slow creep, combined with the high resistivity and heat generation of aluminium oxidation at joints. Spring-loaded contacts have largely alleviated this problem with aluminium conductors in building wire, but some building codes still forbid the use of aluminium.

For branch-circuit sizes, virtually all basic wiring for lights, outlets and switches is made from copper.[19] The market for aluminium building wire today is mostly confined to larger gauge sizes used in supply circuits.[29]

3.3.2 Communications wire (for telephone, cable TV, Ethernet)

Twisted pair cable

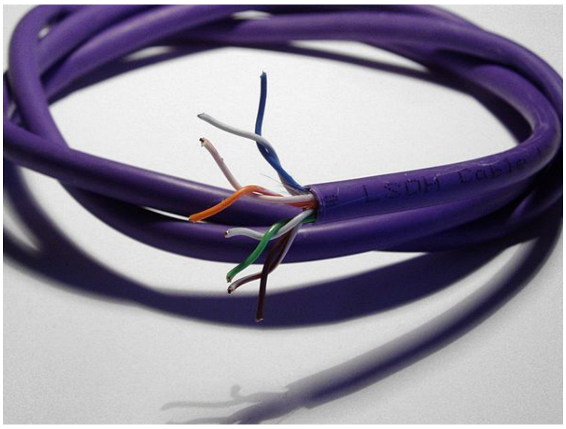
Twisted pair cabling is the most popular network cable and is often used in data networks for short and medium length connections (up to 100 meters or 328 feet).[30] This is due to its relatively lower costs compared to optical fiber and coaxial cable.

Unshielded twisted pair (UTP) cables are the primary cable type for telephone usage. In the late 20th century, UTPs emerged as the most common cable in computer networking cables, especially as patch cables or temporary network connections.[31] They are increasingly used in video applications, primarily in security cameras.

UTP plenum cables that run above ceilings and inside walls use a solid copper core for each conductor, which enables the cable to hold its shape when bent. Patch cables, which connect computers to wall plates, use stranded copper wire because they are expected to be flexed during their lifetimes.[30]

UTPs are the best balanced line wires available. However they are the easiest to tap into. When interference and security are concerns, shielded cable or fiber optic cable is often considered.[30]

UTP cables include: Category 3 cable, now the minimum requirement by the FCC (USA) for every telephone connection; Category 5e cable, 100-MHz enhanced pairs for running Gigabit Ethernet (1000Base-T); and Category 6 cable, where each pair runs 250 MHz for improved 1000Base-T performance.[31][32]



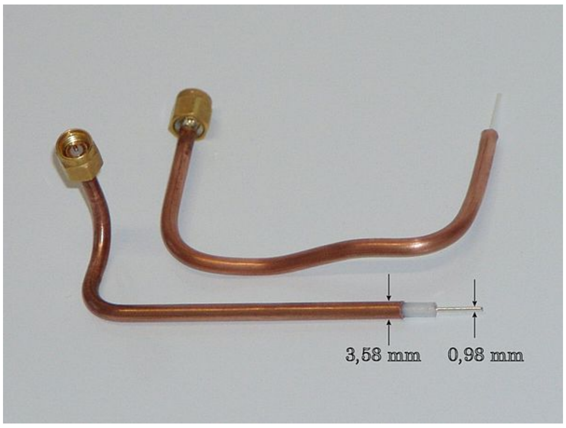
Cat5e ethernet cable, showing the twisted pairs of copper wires.

In copper twisted pair wire networks, copper cable certification is achieved through a thorough series of tests in accordance with Telecommunications Industry Association (TIA) or International Organization for Standardization (ISO) standards.

Coaxial cable

Coaxial cables were extensively used in mainframe computer systems and were the first type of major cable used for Local Area Networks (LAN). Common applications for coaxial cable today include computer network (Internet) and instrumentation data connections, video and CATV distribution, RF and microwave transmission, and feedlines connecting radio transmitters and receivers with their antennas.[33]

While coaxial cables can go longer distances and have better protection from EMI than twisted pairs, coaxial



Semi-rigid coaxial cable for microwave transmission

cables are harder to work with and more difficult to run from offices to the wiring closet. For these reasons, it is now generally being replaced with less expensive UTP cables or by fiber optic cables for more capacity.[30]

Today, many CATV companies still use coaxial cables into homes. These cables, however, are increasingly connected to a fiber optic data communications system outside of the home. Most building management systems use proprietary copper cabling, as do paging/audio speaker systems. Security monitoring and entry systems still often depend on copper, although fiber cables are also used.[34]

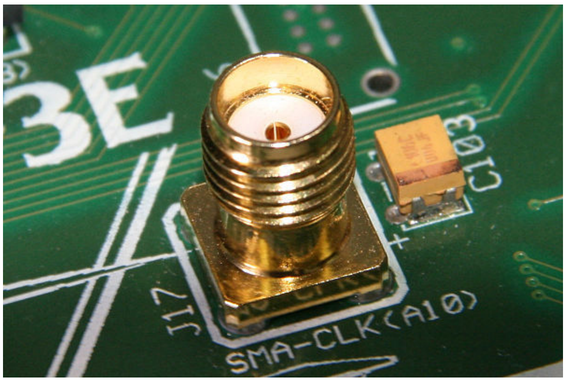
Structured wiring

Most telephone lines can share voice and data simultaneously. Pre-digital quad telephone wiring in homes is unable to handle communications needs for multiple phone lines, Internet service, video communications, data transmission, fax machines, and security services. Crosstalk, static interference, inaudible signals, and interrupted service are common problems with outdated wiring. Computers connected to old-fashioned communications wiring often experience poor Internet performance.

“Structured wiring” is the general term for 21st century On-premises wiring for high-capacity telephone, video, data-transmission, security, control, and entertainment systems. Installations usually include a central distribution panel where all connections are made, as well as outlets with dedicated connections for phone, data, TV and audio jacks.

Structured wiring enables computers to communicate with each other error-free and at high speeds while resisting interference among various electrical sources, such as household appliances and external communications signals. Networked computers are able to share high-speed Internet connections simultaneously. Structured wiring can also connect computers with printers, scanners, telephones, fax machines, and even home security systems and home entertainment equipment.

Copper Category 5 unshielded twisted pair (UTP) wires is the standard for carrying Internet, computer communications, and telephone signals. Category 5 has an rated bandwidth of 100 MHz (megahertz), which is greater than a 56 Kb per second modem. Category 5 is increasingly being supplanted by a higher-speed version, known as Category 5e ("e" for enhanced). Category 6, which will likely accommodate at least twice the bandwidth of Category 5, will be able to carry at least 1 gigabit (billion bits) per second. This equates to about 50,000 pages of text per second.[35]



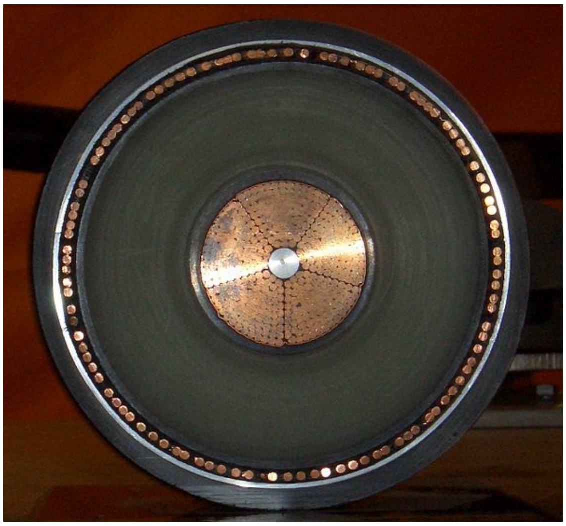
Female socket connector for coaxial cable.

Quad-shielded RG-6 coaxial cable can carry a large number of TV channels at the same time. A star wiring pattern, where the wiring to each jack extends to a central distribution device, facilitates flexibility of services, problem identification, and better signal quality. This pattern has advantages to daisy chain loops. Installation tools, tips, and techniques for networked wiring systems using twisted pairs, coaxial cables, and connectors for each are available.[35][36]

Structured wiring competes with wireless systems in homes. While wireless systems certainly have convenience advantages, they also have drawbacks over copper-wired systems: the higher bandwidth of systems using Category 5e wiring typically support more than ten times the speeds of wireless systems for faster data applications and more channels for video applications. Alternatively, wireless systems are a security risk as they can transmit sensitive information to unintended users over similar receiver devices. Wireless systems are more susceptible to interference from other devices and systems, which can compromise performance.[37] Certain geographic areas and some buildings may be unsuitable for wireless installations, just as some buildings may present difficulties installing wires.

3.3.3 Power distribution

Power distribution is the final stage in the delivery of electricity for an end use. A power distribution system carries electricity from the transmission system to consumers.



Cross-section of copper high-voltage cable rated at 400 kV

Copper is widely used for power distribution bus bars because of its high conductivity

Power cables are used for the transmission and distribution of electric power, either outdoors or inside buildings. Details on the various types of power cables are available.[38]

Copper is the preferred conductor material for underground transmission lines operating at high and extra-high voltages to 400 kV. The predominance of copper underground systems stems from its higher volumetric electrical and thermal conductivities compared to other conductors. These beneficial properties for copper conductors conserve space, minimize power loss, and maintain lower cable temperatures.

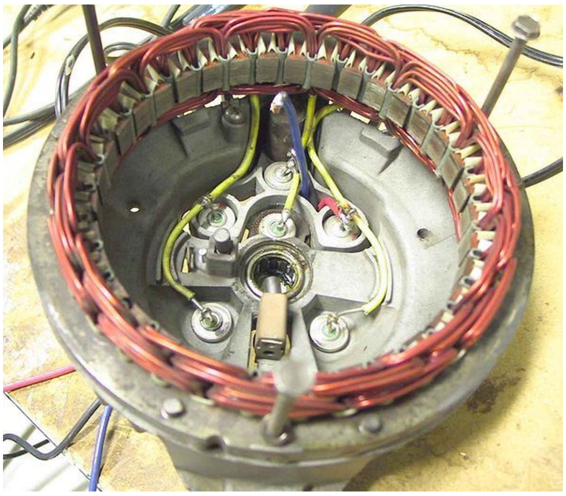
Copper continues to dominate low-voltage lines in mines and underwater applications, as well as in electric railroads, hoists, and other outdoor services.[5]

Aluminium, either alone or reinforced with steel, is the preferred conductor for overhead transmission lines due to its lighter weight and lower cost.[5]

3.3.4 Appliance wire

Appliance wire for domestic applications and instruments is manufactured from bunch-stranded soft wire, which may be tinned for soldering or phase identification. Depending upon loads, insulation can be PVC, neoprene, ethylene propylene, polypropylene filler, or cotton.[5]

3.3.5 Automotive wire and cable



Copper wiring is strong enough to remain in place in an automotive alternator, subjected to constant vibration and mechanical shock.

Automotive wire and cable requires insulation that is resistant to elevated temperatures, petroleum products, humidity, fire, and chemicals. PVC, neoprene, and polyethylene are the most common insulators. Potentials range from 12 V for electrical systems to between 300 V - 15,000 V for instruments, lighting, and ignition systems.[38]

3.3.6 Magnet wire (Winding wire)

Magnet wire is used in windings of electric motors, transformers, inductors, generators, headphones, loudspeaker coils, hard drive head positioners, electromagnets, and other devices.[5][10]

The most suitable materials for magnet wire applications are unalloyed pure metals, particularly copper and aluminium. When factors such as chemical, physical, and mechanical property requirements are considered, copper is considered the first choice conductor for magnet wire.[10]

Most often, magnetic wire is composed of fully annealed, electrolytically refined copper to allow closer winding when making electromagnetic coils. The wire is coated with a range of polymeric insulations, including varnish, rather than the thicker plastic or other types of insulation commonly used on electrical wire.[5]

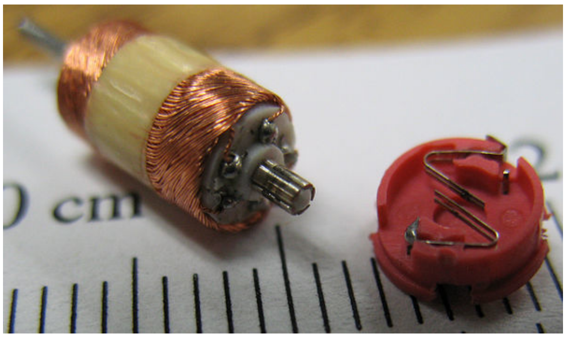
Aluminium magnet wire is sometimes used as an alternative for large transformers and motors. Because of its lower electrical conductivity, aluminium wire requires a 1.6-times larger cross sectional area than a copper wire to achieve comparable DC resistance.

High-purity oxygen-free copper grades are used for high-temperature applications in reducing atmospheres or in motors or generators cooled by hydrogen gas.

Magnet wire in electric motors

Main article: Copper in energy efficient motors

Electric motors convert electrical energy into mechan-



Copper windings in a miniaturized electric motor

ical motion, usually through the interaction of magnetic fields and current-carrying conductors. Electric motors are found in numerous diverse applications, such as fans, blowers, pumps, machines, household appliances, power tools, and disk drives. The very largest electric motors with ratings in the thousands of kilowatts are used in such applications as the propulsion of large ships. The smallest motors move the dials in electric wristwatches.

Electric motors contain coils to produce the required magnetic fields. For a given size of motor frame, high conductivity material allows the coils to be smaller to achieve the same level of loss due to coil resistance. Poorer conductors generate more waste heat when transferring electrical energy into kinetic energy.[39]

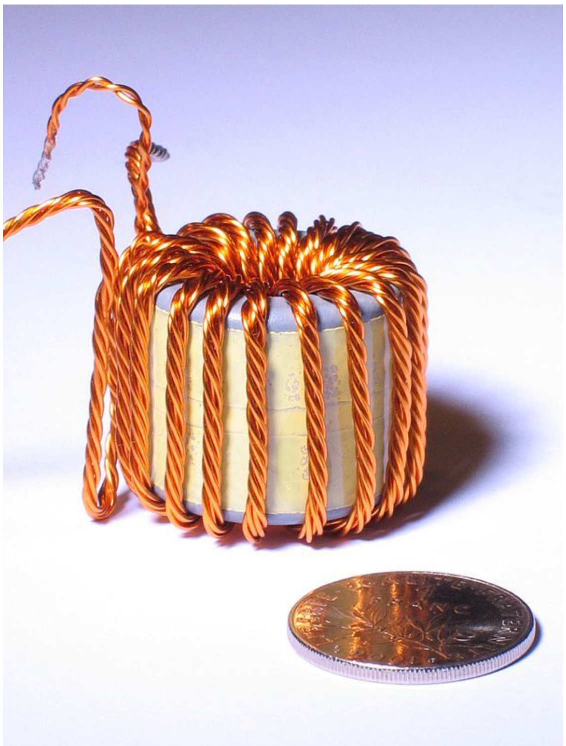
Because of its high electrical conductivity, copper is commonly used in coil windings, bearings, collectors, brushes, and connectors of motors, including the highest quality motors. Copper's greater conductivity versus other materials enhances the electrical energy efficiency of motors. For example, to reduce load losses in continuous-use induction-type motors above 1 horsepower, manufacturers invariably use copper as the conducting material in windings. Aluminium is an alternate material in smaller horsepower motors, especially when motors are not used continuously.

One of the design elements of premium motors is the reduction of heat losses due to the electrical resistance of conductors. To improve the electrical energy efficiencies of induction-type motors, load loss can be reduced by increasing the cross section of copper coils. A high efficiency motor will usually have 20% more copper in the stator winding than its standard counterpart.

Early developments in motor efficiency focused on reducing electrical losses by increasing the packing weight of stator windings. This made sense since electrical losses typically account for more than half of all energy losses, and stator losses account for approximately two-thirds of electrical losses.

There are, however, disadvantages in increasing the electrical efficiency of motors through larger windings. This increases motor size and cost, which may not be desirable in applications such as appliances and in automobiles.[40]

Magnet wire in transformers



Stranded copper Litz wire is used for certain high-frequency transformers

A transformer is a device that transfers electrical energy from one circuit to another through its coils (windings). The properties needed for motor windings are similar to those needed for transformers, but with the additional requirement to withstand mechanical vibration and centrifugal forces at operating temperatures.[41]

Transformer windings are normally made from copper but aluminium is a suitable competitor where weight and first cost are decisive factors.[5]

In North America, aluminium is the predominant choice of winding material for low-voltage, dry-type transformers larger than 15 kilovolt-amperes (kVA). In most other areas of the world, copper is the predominant winding material. Purchasing decisions are generally a function of loss valuations expressed in currency per kilowatt.[14]

Copper used for the manufacture of transformer windings is in the form of wire for small products and strip for larger equipment. For small products, the wire must be strong enough to be wound without breakage, yet flexible enough to provide close-packed windings. Strip products must be of good surface quality so that insulating enamels do not break down under voltage. Good ductility is essential for the strip to be formed and packed while good strength is needed to withstand the high electromechanical stresses set up under occasional short-circuit conditions. Copper winding wires in transformers are compatible with all modern insulation materials, such as lacquer and enamel. Lacquers permit the close spacing of windings to give best efficiency in the coils.[41]

A major engineering reason to choose copper windings over aluminium is space considerations. This is because a copper-wound transformer can be made smaller than aluminium transformers. To obtain equal ratings in aluminium transformers, a 66% larger cross-sectional area is required than for copper conductors. However, the use of larger-sized conductors results in aluminium winding strength nearly equivalent to copper windings.[14]

Connectivity is another important benefit of copper-wound transformers. Cleaning and brushing with a quality joint compound to prevent oxidation is not necessary with copper.[14]

Magnet wire in generators

The trend in modern generators is to operate at higher temperatures and higher electrical conductivities with oxygen-free copper for field bars and magnetic wire in place of formerly used deoxidized copper.[5]

3.4 Splice closures for copper cable

A copper splice closure is defined as an enclosure, and the associated hardware, that is intended to restore the mechanical and environmental integrity of one or more copper cables entering the enclosure and providing some internal function for splicing, termination, or interconnection.[42]

3.4.1 Types of closures

As stated in Telcordia industry requirements document GR-3151, there are two principal configurations for closures: butt closures and in-line closures. Butt closures permit cables to enter the closure from one end only. This design may also be referred to as a dome closure. These closures can be used in a variety of applications, including branch splicing. In-line closures provide for the entry of cables at both ends of the closure. They can be used in a variety of applications, including branch splicing and cable access. In-line closures can also be used in a butt configuration by restricting cable access to one end of the closure.

A copper splice closure is defined by the functional design characteristics and, for the most part, is independent of specific deployment environments or applications. At this time, Telcordia has identified two (2) types of copper closures:

1. Environmentally Sealed Closures (ESCs)
2. Free-Breathing Closures (FBCs)

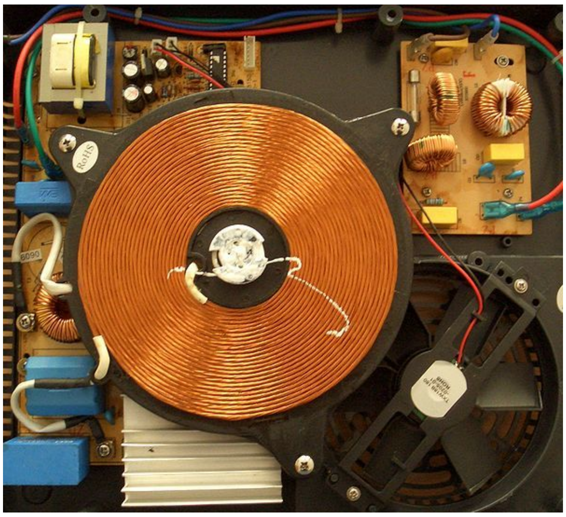
ESCs provide all of the features and functions expected of a typical splice closure in an enclosure that prevents the intrusion of liquid and vapor into the closure interior. This is accomplished through the use of an environmental sealing system such as rubber gaskets or hot-melt adhesives. Some ESCs use pressurized air to help keep moisture out of the closure.

FBCs provide all of the features and functions expected of a typical splice closure that prevents the intrusion of wind-driven rain, dust, and insects. Such a closure, however, permits the free exchange of air with the outside environment. Therefore, it is possible that condensation will form inside the closure. It is thus necessary to provide adequate drainage to prevent the accumulation of water inside the closure.

3.5 Some future trends

Copper will continue to be the predominant material in most electrical wire applications, especially where space considerations are important.[3] The automotive industry for decades has considered the use of smaller-diameter wires in certain applications. Many manufacturers are beginning to use copper alloys such as copper-magnesium (CuMg), which allow for smaller diameter wires with less weight and improved conductivity performance. Special alloys like copper-magnesium are beginning to see increased usage in automotive, aerospace, and defense applications.[43]

Due to the need to increase the transmission of high-speed voice and data signals, the surface quality of copper wire is expected to continue to improve. Demands for



Multiple copper coils are used in an induction cooker

better drawability and movement towards “zero” defects in copper conductors are expected to continue.

A minimum mechanical strength requirement for magnet wire may evolve in order to improve formability and prevent excessive stretching of wire during high speed coiling operations.

It does not seem likely that standards for copper wire purity will increase beyond the current minimum value of 101% IACS. Although 6-nines copper (99.9999% pure) has been produced in small quantities, it is extremely expensive and probably unnecessary for most commercial applications such as magnet, telecommunications, and building wire. The electrical conductivity of 6-nines copper and 4-nines copper (99.99% pure) is nearly the same at ambient temperature, although the higher-purity copper has a higher conductivity at cryogenic temperatures. Therefore, for non-cryogenic temperatures, 4-nines copper will probably remain the dominant material for most commercial wire applications.[3]

3.6 See also

- Wire
- Cable
- Earthing system
- Copper-clad steel
- Copper-clad aluminum
- Mineral-insulated copper-clad cable
- Copper cable certification

3.7 References

[1] Sturgeon, W., 1825, Improved Electro Magnetic Apparatus, *Trans. Royal Society of Arts, Manufactures, & Commerce* (London) 43: pp. 37–52, as cited in Miller, T.J.E, 2001, Electronic Control of Switched Reluctance Machines, *Newnes*, p. 7. ISBN 0-7506-5073-7

[2] Windelspecht, Michael, 2003, Groundbreaking Scientific Experiments, Inventions, and Discoveries of the 19th Century, XXII, Greenwood Publishing Group, ISBN 0-313-31969-3

[3] Pops, Horace, 2008, Processing of wire from antiquity to the future, Wire Journal International, June, pp 58-66

[4] The Metallurgy of Copper Wire, http://www.litz-wire.com/pdf%20files/Metallurgy_Copper_Wire.pdf

[5] Joseph, Günter, 1999, Copper: Its Trade, Manufacture, Use, and Environmental Status, edited by Kundig, Konrad J.A., ASM International Vol. 2.03, Electrical Conductors

[6] "Copper, Chemical Element - Overview, Discovery and naming, Physical properties, Chemical properties, Occurrence in nature, Isotopes". Chemistryexplained.com. Retrieved 2013-06-01.

[7] "The International Annealed Copper Standard; NDT Resources Center". Ndt-ed.org. Retrieved 2013-06-07.

[8] Copper Wire Tables; Circular of the Bureau of Standards; No. 31; S. W. Stratton, Director; U.S. Department of Commerce; 1914

[9] Mott, N.F. and Jones, H., 1958, The theory of the properties of metals and alloys, Dover Publications

[10] Pops, Horace, 1995, Physical Metallurgy of Electrical Conductors, in Nonferrous Wire Handbook, Volume 3: Principles and Practice, The Wire Association International, pp. 7-22

[11] Copper Building Wire Systems, Copper Development Association, Inc.

[12] "Copper — Properties and Applications". Copper-info.co.uk. Retrieved 2013-06-01.

[13] "The Metallurgy of Copper Wire" (PDF). Retrieved 2013-06-07.

[14] "VTI : Aluminum vs. Copper: Conductors in Low Voltage Dry Type Transformers". Vt-inc.com. 2006-08-29. Retrieved 2013-06-01.

[15] http://www.geindustrial.com/Newsletter/Aluminum_vs_Copper.pdf

[16] Weast, Robert C. & Shelby, Samuel M. Handbook of Chemistry and Physics, 48th edition, Ohio: The Chemical Rubber Co. 1967–1968: F-132

[17] W.F. Gale; T.C. Totemeir, eds. (2004), *Smithells Metals Reference Book* (8th ed.), Elsevier Butterworth Heinemann Co. and ASM International, ISBN 0-7506-7509-8

[18] "Development of Aluminum Alloy Conductor with High Electrical Conductivity and Controlled Tensile Strength and Elongation" (PDF). Retrieved 2013-06-07.

[19] "Electrical: Building Wire - Copper Building Wire Systems". Copper.org. 2010-08-25. Retrieved 2013-06-01.

[20] Rich, Jack C., 1988, The Materials and Methods of Sculpture. Courier Dover Publications. p. 129. ISBN 0-486-25742-8, http://books.google.com/?id=hW13qhOFa7gC

[21] Nonferrous Wire Handbook, Volume 3: Principles and Practice, The Wire Association International

[22] Pops, Horace; Importance of the conductor and control of its properties for magnet wire applications, in Nonferrous Wire Handbook, Volume 3: Principles and Practice, The Wire Association International, pp 37-52

[23] "Electrical: Building Wire - Copper, The Best Buy". Copper.org. 2010-08-25. Retrieved 2013-06-01.

[24] "Wire & Cable, Communications, Security and Fasteners" (PDF). Anixter. Retrieved 2013-06-01.

[25] *Telephony* by T.E. Herbert & W.S. Procter,Volume 1 p1110 (1946, Pitman, London)

[26] Copper Building Wire, Copper/Brass/Bronze Products Handbook, CDA Publication 601/0, Copper Development Association

[27] The International Annealed Copper Standard; NDT Resources Center; http://www.ndt-ed.org/GeneralResources/IACS/IACS.htm

[28] "Applications: Telecommunications - All-Copper Wiring". Copper.org. 2010-08-25. Retrieved 2013-06-01.

[29] Davis, Joseph R., Copper and copper alloys, ASM International. Handbook Committee, pp. 155-156

[30] "Network+, Module 3 - The Physical Network". Lrgnetworks.com. Retrieved 2013-06-01.

[31] "Selecting coax and twisted-pair cable". .electronicproducts.com. Retrieved 2013-06-01.

[32] "The Evolution of Copper Cabling Systems from Cat5 to Cat5e to Cat6" (PDF).www.panduit.com

[33] Van Der Burgt, Martin J., 2011, "Coaxial Cables and Applications". Belden. p. 4. Retrieved 11 July 2011, http://www.belden.com/pdfs/Techpprs/CoaxialCablesandApplications.pdf

[34] http://www.thefoa.org/tech/guides/DesG.pdf

[35] "Applications: Telecommunications - Communications Wiring for Today's Homes". Copper.org. 2010-08-25. Retrieved 2013-06-01.

[36] "Applications: Telecommunications - Infrastructure Wiring for Homes". Copper.org. 2010-08-25. Retrieved 2013-06-01.

[37] Structured wiring for today's homes (CD-ROM), Copper Development Association, NY, NY, USA

[38] Electric Wire and Cable, brochure 0001240, Cobre Cerrillos S.A., Santiago, Chile; Cocessa Technical Bulletin, Electrical Conductor Catalog 751, MADECO, 1990

[39] "Electric Motors (for 14 to 16 year-olds)". Eurocopper.org. Retrieved 2013-06-01.

[40] The emerging electrical markets for copper, Bloomsbury Minerals Economics LTD, July 6, 2010

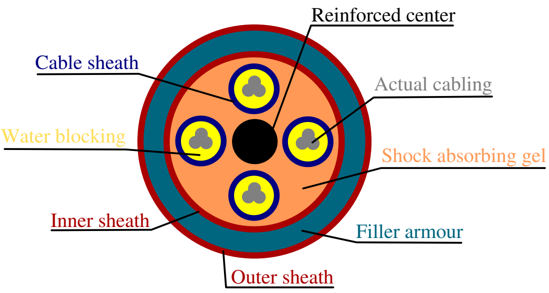
[41] "Find out why we prefer to make cables and wires out of copper!". Eurocopper.org. Retrieved 2013-06-01.

[42] GR-3151-CORE, Generic Requirements for Copper Splice Closures, Telcordia.

[43] "C18661 Copper-Magnesium (CMG1) Alloy Wire". *Fisk (website)*. Fisk Alloy, Inc. Retrieved 19 March 2013.

Chapter 4

Direct-buried cable



Cross-section of direct buried cable

Direct-buried cable (DBC) is a kind of communications or transmissions cable which is especially designed to be buried under the ground without any kind of extra covering, sheathing, or piping to protect it.[1]

Most direct-buried cable is built to specific tolerances to heat, moisture, conductivity, and soil acidity. Unlike standard telecommunications and power cables, which have only a thin layer of insulation and a waterproof outer cover, DBC consists of multiple layers of heavy metallic-banded sheathing, reinforced by heavy rubber covers, shock absorbing gel, wrapped thread-fortified waterproof tape, and stiffened by a heavy metal core.

DBC is preferable in some areas since it is more resistant to being the focus of lightning discharges.[2]

4.1 Communications

Most cable of this kind is coaxial or bundled fiber-optic in nature. Direct-buried cable is cheaper and easier to lay than other kinds of cable that require protection from the earth.[1] However, DBC is also easily cut during digging or other excavations. As a result, most direct-buried cable is found on side roads, not main thoroughfares.[3]

4.2 Power

Some power cabling is also direct-buried. This kind of cabling must follow strict regulatory procedures regarding installation [4] and backfilling. This is usually used for undergrounding in areas where overhead cabling is impractical or dangerous.

4.3 External links

- Guide to direct buried cabling procedures

4.4 References

[1] Sterling, Donald J. (2000). *Premises Cabling*. Thomson Delmar Learning. ISBN 0-7668-1735-0.

[2] Rakov, Vladimir A.; Uman, Martin A. (2003). *Lightning: physics and effects*. Cambridge University Press. ISBN 0-521-58327-6.

[3] Highhouse, John (1997). *A Guide for Telecommunications Cable Splicing*. Thomson Delmar Learning. ISBN 0-8273-8066-6.

[4] Salata F., De Lieto Vollaro A., De Lieto Vollaro R. A model for the evaluation of heat loss from underground cables in non-uniform soil to optimize the system design. Thermal Science, DOI REFERENCE: 10.2298/TSCI120528119S

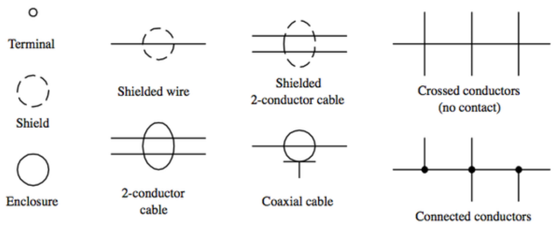
Chapter 5

Electrical wiring

"Wiring" redirects here. For the software development platform, see Wiring (development platform).
This article is about building wiring. For power distribution, see Electric power transmission and Electric power distribution.

Building wiring is the electrical wiring and associated devices such as switches, meters and light fittings used in buildings or other structures. Electrical wiring uses insulated conductors.

5 core PVC insulated copper cable



Electronic symbols for wiring

Wiring safety codes vary by country, and the International Electrotechnical Commission (IEC) is attempting to standardise wiring amongst member countries. Wires and cables are rated by the circuit voltage, temperature and environmental conditions (moisture, sunlight, oil, chemicals) in which they can be used. Colour codes are used to distinguish line, neutral and ground (earth) wires.

5.1 Wiring safety codes

Main article: Electrical codes

Wiring safety codes are intended to protect people and property from electrical shock and fire hazards. Regulations may be established by city, county, provincial/state or national legislation, usually by adopting a model code (with or without local amendments) produced by a technical standards-setting organisation, or by a national standard electrical code.

Electrical codes arose in the 1880s with the commercial introduction of electrical power. Many conflicting standards existed for the selection of wire sizes and other design rules for electrical installations.

The first electrical codes in the United States originated in New York in 1881 to regulate installations of electric lighting. Since 1897 the US National Fire Protection Association, a private non-profit association formed by insurance companies, has published the *National Electrical Code* (NEC). States, counties or cities often include the NEC in their local building codes by reference along with local differences. The NEC is modified every three years. It is a consensus code considering suggestions from interested parties. The proposals are studied by committees of engineers, tradesmen, manufacturer representatives, fire fighters and other invitees.

Since 1927, the Canadian Standards Association (CSA) has produced the Canadian *Safety Standard for Electrical Installations*, which is the basis for provincial electrical codes. The CSA also produces the Canadian Electrical

Code, the 2006 edition of which references IEC 60364 (*Electrical Installations for Buildings*) and states that the code addresses the fundamental principles of electrical protection in Section 131. The Canadian code reprints Chapter 13 of IEC 60364, but there are no numerical criteria listed in that chapter to assess the adequacy of any electrical installation.

Although the US and Canadian national standards deal with the same physical phenomena and broadly similar objectives, they differ occasionally in technical detail. As part of the North American Free Trade Agreement (NAFTA) program, US and Canadian standards are slowly converging toward each other, in a process known as harmonisation.

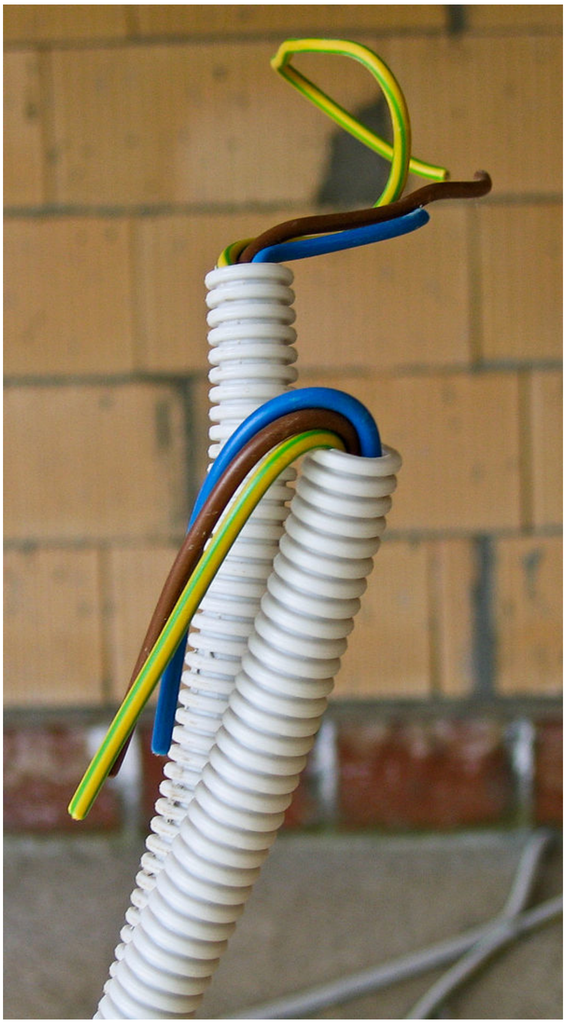
In Germany, DKE (the German Commission for Electrical, Electronic and Information Technologies of DIN and VDE) is the organisation responsible for the promulgation of electrical standards and safety specifications. DIN VDE 0100 is the German wiring regulations document harmonised with IEC 60364.

In the United Kingdom, wiring installations are regulated by the Institution of Engineering and Technology *Requirements for Electrical Installations: IEE Wiring Regulations, BS 7671: 2008,* which are harmonised with IEC 60364. The 17th edition (issued in January 2008) includes new sections for microgeneration and solar photovoltaic systems. The first edition was published in 1882.

In Australia and New Zealand, the AS/NZS 3000 standard, commonly known as the “wiring rules”, specifies requirements for the selection and installation of electrical equipment, and the design and testing of such installations. The standard is mandatory in both New Zealand and Australia; therefore, all electrical work covered by the standard must comply.

In European countries, an attempt has been made to harmonise national wiring standards in an IEC standard, IEC 60364 *Electrical Installations for Buildings*. Hence national standards follow an identical system of sections and chapters. However, this standard is not written in such language that it can readily be adopted as a national wiring code. Neither is it designed for field use by electrical tradesmen and inspectors for testing compliance with national wiring standards. By contrast, national codes, such as the NEC or CSA C22.1, generally exemplify the common objectives of IEC 60364, but provide specific rules in a form that allows for guidance of those installing and inspecting electrical systems.

The international standard wire sizes are given in the IEC 60228 standard of the International Electrotechnical Commission. In North America, the American Wire Gauge standard for wire sizes is used.



An electrical “3G” power cable found commonly in modern European houses. The cable consists of 3 wires (2 wires + 1 grounding in case if cable has “3G” name) and is double-insulated.

5.2 Colour code

To enable wires to be easily and safely identified, all common wiring safety codes mandate a colour scheme for the insulation on power conductors. In a typical electrical code, some colour-coding is mandatory, while some may be optional. Many local rules and exceptions exist. Older installations vary in colour codes, and colours may fade with insulation exposure to heat, light and ageing.

Many electrical codes now recognise (or even require) the use of wire covered with green insulation, additionally marked with a prominent yellow stripe, for safety earthing (grounding) connections. This growing international standard was adopted for its distinctive appearance, to reduce the likelihood of dangerous confusion of safety earthing (grounding) wires with other electrical functions, especially by persons affected by red-green colour blindness.

The down side of the use of International colours is that, in the UK for example, phases could be identified as being live by using coloured indicator lights: red, yellow and blue. The new cable colours of brown, black and grey do not lend themselves to coloured indicators. For this reason, three-phase control panels will often use indicator lights of the old colours.

5.3 Wiring methods

Installing electrical wiring by cutting into the bricks of the building

Materials for wiring interior electrical systems in buildings vary depending on:

- Intended use and amount of power demand on the circuit
- Type of occupancy and size of the building
- National and local regulations
- Environment in which the wiring must operate.

Wiring systems in a single family home or duplex, for example, are simple, with relatively low power requirements, infrequent changes to the building structure and layout, usually with dry, moderate temperature and non-corrosive environmental conditions. In a light commercial environment, more frequent wiring changes can be expected, large apparatus may be installed and special conditions of heat or moisture may apply. Heavy industries have more demanding wiring requirements, such as very large currents and higher voltages, frequent changes of equipment layout, corrosive, or wet or explosive atmospheres. In facilities that handle flammable gases or liquids, special rules may govern the installation and wiring of electrical equipment in hazardous areas.

Wires and cables are rated by the circuit voltage, temperature rating and environmental conditions (moisture, sunlight, oil, chemicals) in which they can be used. A wire or cable has a voltage (to neutral) rating and a maximum conductor surface temperature rating. The amount of current a cable or wire can safely carry depends on the installation conditions.

5.3.1 Early wiring methods

The first interior power wiring systems used conductors that were bare or covered with cloth, which were secured by staples to the framing of the building or on running boards. Where conductors went through walls, they were protected with cloth tape. Splices were done similarly to telegraph connections, and soldered for security. Underground conductors were insulated with wrappings of cloth tape soaked in pitch, and laid in wooden troughs which were then buried. Such wiring systems were unsatisfactory because of the danger of electrocution and fire, plus the high labour cost for such installations.

5.3.2 Knob and tube

Main article: Knob and tube wiring

The earliest standardised method of wiring in buildings,

Knob-and-tube wiring (the lower pipe is an unrelated copper water line)

in common use in North America from about 1880 to the 1930s, was *knob and tube* (K&T) wiring: single conductors were run through cavities between the structural members in walls and ceilings, with ceramic tubes forming protective channels through joists and ceramic knobs attached to the structural members to provide air between the wire and the lumber and to support the wires. Since air was free to circulate over the wires, smaller conductors could be used than required in cables. By arranging wires on opposite sides of building structural members, some protection was afforded against short-circuits that can be caused by driving a nail into both conductors simultaneously.

By the 1940s, the labour cost of installing two conductors rather than one cable resulted in a decline in new knob-and-tube installations. However, the US code still allows new K&T wiring installations in special situations (some rural and industrial applications).

5.3.3 Metal-sheathed wires

In the United Kingdom, an early form of insulated cable,[1] introduced in 1896, consisted of two impregnated-paper-insulated conductors in an overall lead sheath. Joints were soldered, and special fittings were used for lamp holders and switches. These cables were similar to underground telegraph and telephone cables of the time. Paper-insulated cables proved unsuitable for interior wiring installations because very careful workmanship was required on the lead sheaths to ensure moisture did not affect the insulation.

A system later invented in the UK in 1908 employed vulcanised-rubber insulated wire enclosed in a strip metal sheath. The metal sheath was bonded to each metal wiring device to ensure earthing continuity.

A system developed in Germany called “Kuhlo wire” used one, two, or three rubber-insulated wires in a brass or lead-coated iron sheet tube, with a crimped seam. The enclosure could also be used as a return conductor. Kuhlo wire could be run exposed on surfaces and painted, or embedded in plaster. Special outlet and junction boxes were made for lamps and switches, made either of porcelain or sheet steel. The crimped seam was not considered as watertight as the *Stannos* wire used in England, which had a soldered sheath.[2]

A somewhat similar system called “concentric wiring” was introduced in the United States around 1905. In this system, an insulated electrical wire was wrapped with copper tape which was then soldered, forming the grounded (return) conductor of the wiring system. The bare metal sheath, at earth potential, was considered safe to touch. While companies such as General Electric manufactured fittings for the system and a few buildings were wired with it, it was never adopted into the US National Electrical Code. Drawbacks of the system were that special fittings were required, and that any defect in the connection of the sheath would result in the sheath becoming energised.[3]

5.3.4 Other historical wiring methods

Other methods of securing wiring that are now obsolete include:

- Re-use of existing gas pipes when converting gas light installations to electric lighting. Insulated conductors were pulled through the pipes that had formerly supplied the gas lamps. Although used occasionally, this method risked insulation damage from sharp edges inside the pipe at each joint.
- Wood mouldings with grooves cut for single conductor wires, covered by a wooden cap strip. These were prohibited in North American electrical codes by 1928. Wooden moulding was also used to some degree in England, but was never permitted by German and Austrian rules.[4]
- A system of flexible twin cords supported by glass or porcelain buttons was used near the turn of the 20th century in Europe, but was soon replaced by other methods.[5]
- During the first years of the 20th century, various patented forms of wiring system such as Bergman and Peschel tubing were used to protect wiring; these used very thin fiber tubes, or metal tubes which were also used as return conductors.[6]
- In Austria, wires were concealed by embedding a rubber tube in a groove in the wall, plastering over it, then removing the tube and pulling wires through the cavity.[7]

Metal moulding systems, with a flattened oval section consisting of a base strip and a snap-on cap channel, were more costly than open wiring or wooden moulding, but could be easily run on wall surfaces. Similar surface mounted raceway wiring systems are still available today.

5.4 Cables

Main article: Power cable

Armoured cables with two rubber-insulated conductors in a flexible metal sheath were used as early as 1906, and were considered at the time a better method than open knob-and-tube wiring, although much more expensive.

The first rubber-insulated cables for building wiring were introduced in 1922 with US patent 1458803, Burley, Harry & Rooney, Henry, “Insulated electric wire”, issued 1923-06-12, assigned to Boston Insulated Wire And Cable. These were two or more solid copper electrical wires with rubber insulation, plus woven cotton cloth over each conductor for protection of the insulation, with an overall

Wiring for extremely wet conditions

woven jacket, usually impregnated with tar as a protection from moisture. Waxed paper was used as a filler and separator.

Over time, rubber-insulated cables become brittle because of exposure to atmospheric oxygen, so they must be handled with care and are usually replaced during renovations. When switches, outlets or light fixtures are replaced, the mere act of tightening connections may cause hardened insulation to flake off the conductors. Rubber insulation further inside the cable often is in better condition than the insulation exposed at connections, due to reduced exposure to oxygen.

The sulphur in vulcanised rubber insulation attacked bare copper wire so the conductors were tinned to prevent this. The conductors reverted to being bare when rubber ceased to be used.

About 1950, PVC insulation and jackets were introduced, especially for residential wiring. About the same time, single conductors with a thinner PVC insulation and a thin nylon jacket (e.g. US Type THN, THHN, etc.) became common.

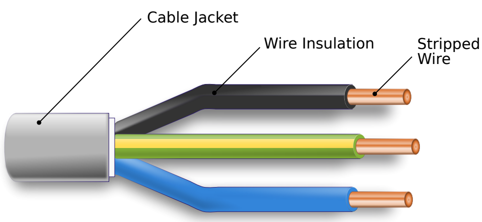


Diagram of a simple electrical cable with three insulated conductors

The simplest form of cable has two insulated conductors twisted together to form a unit; such unjacketed cables with two or three conductors are used for low-voltage signal and control applications such as doorbell wiring. In North American practice, an overhead cable from a transformer on a power pole to a residential electrical service consists of three twisted (triplexed) wires, often with one being a bare wire made of copper (protective earth/ground) and the other two being insulated for the line voltage (hot/line wire and neutral wire). For additional safety, the ground wire may be formed into a stranded co-axial layer completely surrounding the phase conductors, so that the outmost conductor is grounded.

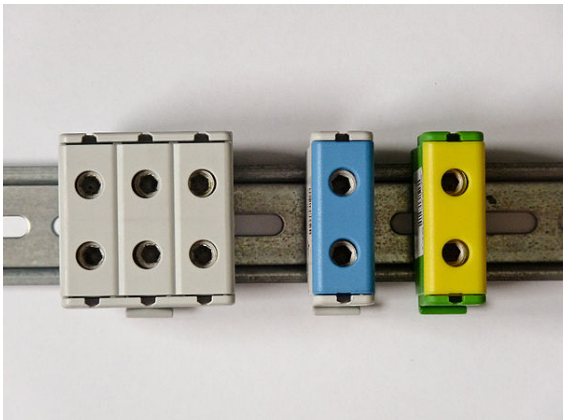
5.4.1 Copper conductors

Main article: Copper wire and cable

Electrical devices often contain copper conductors because of their multiple beneficial properties, including their high electrical conductivity, tensile strength, ductility, creep resistance, corrosion resistance, thermal conductivity, coefficient of thermal expansion, solderability, resistance to electrical overloads, compatibility with electrical insulators and ease of installation.

Despite competition from other materials, copper remains the preferred electrical conductor in nearly all categories of electrical wiring.[8][9] For example, copper is used to conduct electricity in high, medium and low voltage power networks, including power generation, power transmission, power distribution, telecommunications, electronics circuitry, data processing, instrumentation, appliances, entertainment systems, motors, transformers, heavy industrial machinery and countless other types of electrical equipment.[10]

5.4.2 Aluminium conductors



Terminal blocks for joining aluminium and copper conductors. The terminal blocks may be mounted on a DIN rail.

Aluminium wire was common in North American residential wiring from the late 1960s to mid-1970s due to the rising cost of copper. Because of its greater resistivity, aluminium wiring requires larger conductors than copper. For instance, instead of 14 AWG (American wire gauge) for most lighting circuits, aluminium wiring would be 12 AWG on a typical 15 ampere circuit, though local building codes may vary.

Aluminium conductors were originally indiscriminately used with wiring devices intended for copper conductors. This practice was found to cause defective connections unless the aluminium was one of a special alloy, or all devices — breakers, switches, receptacles, splice connectors, wire nuts, etc. — were specially designed for the purpose. These special designs address problems with junctions between dissimilar metals, oxidation on metal surfaces and mechanical effects that occur as different metals expand at different rates with increases in temperature.

Unlike copper, aluminium has a tendency to cold-flow under pressure, so screw clamped connections may get loose over time. This can be mitigated by using spring-loaded connectors that apply constant pressure, applying high pressure cold joints in splices and termination fittings, and torquing the bolted connection.

Also unlike copper, aluminium forms an insulating oxide layer on the surface. This is sometimes addressed by coating aluminium wires with an antioxidant paste at joints, or by applying a mechanical termination designed to break through the oxide layer during installation.

Because of improper design and installation, some junctions to wiring devices would overheat under heavy current load, and cause fires. Revised standards for wiring devices (such as the **CO/ALR** "copper-aluminium-revised" designation) were developed to reduce these problems. Nonetheless, aluminium wiring for residential use has acquired a poor reputation and has fallen out of favour.

Aluminium conductors are still used for bulk power distribution and large feeder circuits, because they cost less than copper wiring, and weigh less, especially in the large sizes needed for heavy current loads. Aluminium conductors must be installed with compatible connectors.

5.4.3 Modern wiring materials

Modern non-metallic sheathed cables, such as (US and Canadian) Types NMB and NMC, consist of two to four wires covered with thermoplastic insulation, plus a bare wire for grounding (bonding), surrounded by a flexible plastic jacket. Some versions wrap the individual conductors in paper before the plastic jacket is applied.

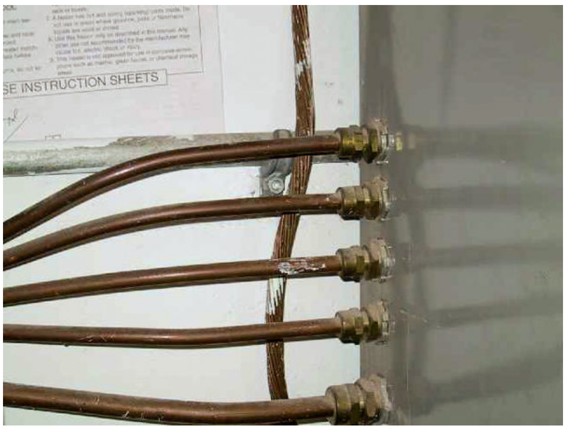
Special versions of non-metallic sheathed cables, such as US Type UF, are designed for direct underground burial (often with separate mechanical protection) or exterior use where exposure to ultraviolet radiation (UV) is a possibility. These cables differ in having a moisture-resistant construction, lacking paper or other absorbent fillers, and being formulated for UV resistance.

Rubber-like synthetic polymer insulation is used in industrial cables and power cables installed underground because of its superior moisture resistance.

Insulated cables are rated by their allowable operating voltage and their maximum operating temperature at the conductor surface. A cable may carry multiple usage ratings for applications, for example, one rating for dry installations and another when exposed to moisture or oil.

Generally, single conductor building wire in small sizes is solid wire, since the wiring is not required to be very flexible. Building wire conductors larger than 10 AWG (or about 6 mm^2) are stranded for flexibility during installation, but are not sufficiently pliable to use as appliance cord.

Cables for industrial, commercial and apartment buildings may contain many insulated conductors in an overall jacket, with helical tape steel or aluminium armour, or steel wire armour, and perhaps as well an overall PVC or lead jacket for protection from moisture and physical damage. Cables intended for very flexible service or in marine applications may be protected by woven bronze wires. Power or communications cables (e.g., computer networking) that are routed in or through air-handling spaces (plenums) of office buildings are required under the model building code to be either encased in metal conduit, or rated for low flame and smoke production.



Mineral insulated cables at a panel board

For some industrial uses in steel mills and similar hot environments, no organic material gives satisfactory service. Cables insulated with compressed mica flakes are sometimes used. Another form of high-temperature cable is a mineral insulated cable, with individual conductors placed within a copper tube and the space filled with magnesium oxide powder. The whole assembly is drawn down to smaller sizes, thereby compressing the powder. Such cables have a certified fire resistance rating and are more costly than non-fire rated cable. They have little flexibility and behave more like rigid conduit rather than flexible cables.

Because multiple conductors bundled in a cable cannot dissipate heat as easily as single insulated conductors, those circuits are always rated at a lower "ampacity". Tables in electrical safety codes give the maximum allowable current for a particular size of conductor, for the voltage and temperature rating at the surface of the conductor for a given physical environment, including the insulation type and thickness. The allowable current will be different for wet or dry, for hot (attic) or cool (underground) locations. In a run of cable through several areas, the most severe area will determine the appropriate rating of the overall run.

Cables usually are secured by special fittings where they enter electrical apparatus; this may be a simple screw clamp for jacketed cables in a dry location, or a polymer-gasketed cable connector that mechanically engages the armour of an armoured cable and provides a water-resistant connection. Special cable fittings may be applied to prevent explosive gases from flowing in the interior of jacketed cables, where the cable passes through areas where inflammable gases are present. To prevent loosening of the connections of individual conductors of a cable, cables must be supported near their entrance to devices and at regular intervals through their length. In tall buildings, special designs are required to support the conductors of vertical runs of cable. Usually, only one cable per fitting is allowed unless the fitting is otherwise rated.

Special cable constructions and termination techniques are required for cables installed in ocean-going vessels; in addition to electrical safety and fire safety, such cables may also be required to be pressure-resistant where they penetrate bulkheads of a ship. Resistance to corrosion caused by salt water or salt spray is also required.

5.5 Raceways

See also: Electrical conduit
Insulated wires may be run in one of several forms of

Electrical conduit risers, seen inside fire-resistance rated shaft, as seen entering bottom of a firestop. The firestop is made of firestop mortar on top, rockwool on the bottom. Raceways are used to protect cables from damage.

a raceway between electrical devices. This may be a specialised bendable pipe, called a conduit, or one of several varieties of metal (rigid steel or aluminium) or non-metallic (PVC or HDPE) tubing. Rectangular cross-section metal or PVC wire troughs (North America) or trunking (UK) may be used if many circuits are required. Wires run underground may be run in plastic tubing encased in concrete, but metal elbows may be used in severe pulls. Wiring in exposed areas, for example factory floors, may be run in cable trays or rectangular raceways having lids.

Where wiring, or raceways that hold the wiring, must traverse fire-resistance rated walls and floors, the openings are required by local building codes to be firestopped. In cases where safety-critical wiring must be kept operational during an accidental fire, fireproofing must be applied to maintain circuit integrity in a manner to comply with a product's certification listing. The nature and thickness of any passive fire protection materials used in conjunction with wiring and raceways has a quantifiable impact upon the ampacity derating, because the thermal insulation properties needed for fire resistance also inhibit air cooling of power conductors.

A cable tray can be used in stores and dwellings

Cable trays are used in industrial areas where many insulated cables are run together. Individual cables can exit the tray at any point, simplifying the wiring installation and reducing the labour cost for installing new cables. Power cables may have fittings in the tray to maintain clearance between the conductors, but small control wiring is often installed without any intentional spacing between cables.

Since wires run in conduits or underground cannot dissipate heat as easily as in open air, and since adjacent circuits contribute induced currents, wiring regulations give rules to establish the current capacity (ampacity).

Special sealed fittings are used for wiring routed through potentially explosive atmospheres.

5.6 Bus bars, bus duct, cable bus

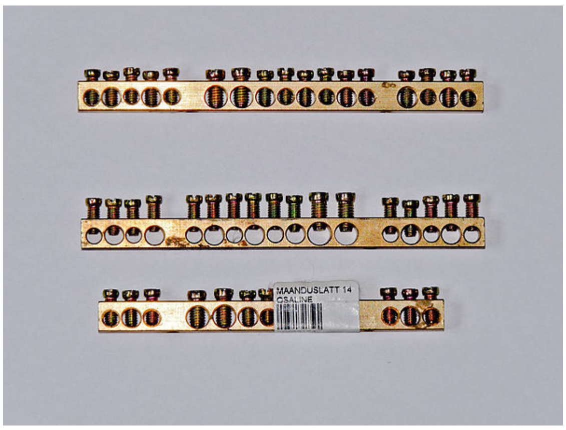
Main article: Bus bar

For very high currents in electrical apparatus, and for

Topside of firestop with penetrants consisting of electrical conduit on the left and a bus duct on the right. The firestop consists of firestop mortar on top and rockwool on the bottom, for a 2 hour fire-resistance rating.

high currents distributed through a building, bus bars can be used. (The term "bus" is a contraction of the Latin *omnibus* - meaning "for all".) Each live conductor of such a system is a rigid piece of copper or aluminium, usually in flat bars (but sometimes as tubing or other shapes). Open bus bars are never used in publicly accessible areas, although they are used in manufacturing plants and power company switch yards to gain the benefit of air cooling. A variation is to use heavy cables, especially where it is desirable to transpose or "roll" phases.

In industrial applications, conductor bars are often pre-assembled with insulators in grounded enclosures. This assembly, known as bus duct or busway, can be used for connections to large switchgear or for bringing the main power feed into a building. A form of bus duct known as "plug-in bus" is used to distribute power down the length of a building; it is constructed to allow tap-off switches or motor controllers to be installed at designated places along the bus. The big advantage of this scheme is the ability to remove or add a branch circuit without removing voltage from the whole duct.

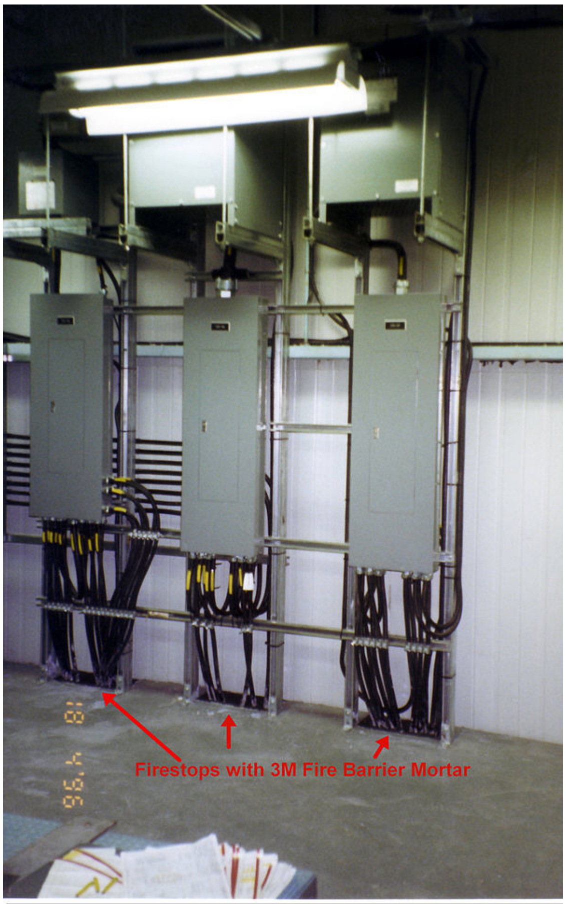


Busbars for distributing PE (ground)

Bus ducts may have all phase conductors in the same enclosure (non-isolated bus), or may have each conductor separated by a grounded barrier from the adjacent phases (segregated bus). For conducting large currents between devices, a cable bus is used.

For very large currents in generating stations or substations, where it is difficult to provide circuit protection, an isolated-phase bus is used. Each phase of the circuit is run in a separate grounded metal enclosure. The only fault possible is a phase-to-ground fault, since the enclosures are separated. This type of bus can be rated up to 50,000 amperes and up to hundreds of kilovolts (during normal service, not just for faults), but is not used for building wiring in the conventional sense.

5.7 Electrical panels



Electrical panels in an electrical service room at St. Mary's Pulp and Paper, Sault Ste. Marie, Ontario, Canada, April 1996

Electrical panels, cables and firestops in an electrical service room at a paper mill in Ontario, Canada

Electrical panels are easily accessible junction boxes used to reroute and switch electrical services. The term is often used to refer to circuit breaker panels or fuseboxes.

5.8 Degradation by pests

Rasberry crazy ants have been known to consume the insides of electrical wiring installations, preferring DC over AC currents. This behaviour is not well understood by scientists.[11]

Squirrels, rats and other rodents may gnaw on unprotected wiring, causing fire and shock hazards.[12][13]

5.9 See also

- 10603 — a frequently used MIL-SPEC compliant wire
- Cable
- Cable Entry System
- Cable tray
- Domestic AC power plugs and sockets
- Electrical conduit
- Electrical room
- Electrical wiring in North America
- Electrical wiring in the United Kingdom
- Electricity distribution
- Grounding
- Home wiring
- Industrial and multiphase power plugs and sockets
- MIL-DTL-13486 — MIL-SPEC compliant wire
- Neutral wire
- OFHC
- Portable cord
- Restriction of Hazardous Substances Directive (RoHS)
- Single-phase electric power
- Structured cabling
- Three-phase electric power

5.10 References

[1] Robert M. Black, *The History of Electric Wires and Cable*, Peter Pergrinus Ltd. London, 1983 ISBN 0-86341-001-4, pp. 155–158

[2] Croft

[3] Schneider, Norman H., *Wiring houses for the electric light; together with special references to low voltage battery systems*, Spon and Chamberlain, New York 1916, pp. 93–98

[4] Croft, p. 142

[5] Croft, p. 143

[6] Croft, p. 136

[7] Croft, p. 137

[8] Pops, Horace (June 2008). "Processing of wire from antiquity to the future". *Wire Journal International*: 58–66.

[9] The Metallurgy of Copper Wire. litz-wire.com

[10] Joseph, Günter, 1999, Copper: Its Trade, Manufacture, Use, and Environmental Status, Kundig, Konrad J.A. (ed.), ASM International, ISBN 0871706563, pp. 141–192, 331–375

[11] Andrew R Hickey (15 May 2008). "'Crazy' Ant Invasion Frying Computer Equipment".

[12] "Guide to Safe Removal". *Squirrels in the Attic*. Retrieved 19 April 2012.

[13] University of Illinois Extension. "Tree Squirrels > Damage Prevention and Control Measures". *Living with Wildlife in Illinois*. University of Illinois Board of Trustees. Retrieved 12 March 2013.

5.11 Bibliography

- Croft, Terrel (1915) *Wiring of Finished Buildings*, McGraw Hill, New York.

5.12 Further reading

- National Electrical Code — Basis of most US electrical codes. Choose NFPA 70 (general purpose) or NFPA 70A (one and two family dwellings). Free registration required.
- National Electrical Code 2011 (2011 ed.), Quincy MA: National Fire Protection Association, 2010. — periodically re-issued every 3 years
- NEMA comparison of IEC 60364 with the US NEC
- Cauldwell, Rex (2002). *Wiring a House (For Pros By Pros)*. Newtown, CT, USA: Taunton Press. ISBN 1-56158-527-0.

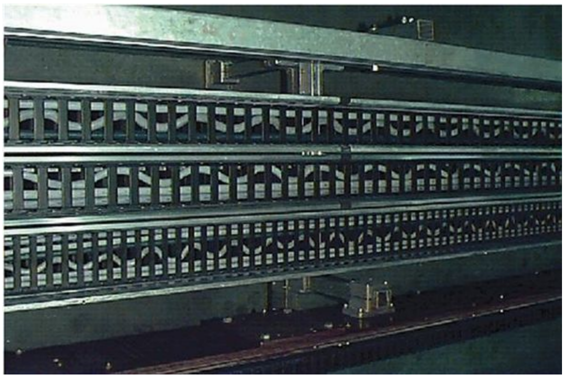
- Hirst, E. Electric Utilities and Energy
- Litchfield, Michael; Michael McAlister (2008). *Taunton's wiring complete : expert advice from start to finish* (Revised ed.). Newtown, CT: Taunton Press. ISBN 978-1-60085-256-5.

5.13 External links

- Electrical wiring FAQ — oriented to US/Canadian practice

Chapter 6

Flexible cable



Standard cables used in cable carriers may risk 'corkscrewing'

Flexible cables, or 'continuous-flex' cables, are cables specially designed to cope with the tight bending radii and physical stress associated with moving applications, such as inside cable carriers.

Due to increasing demands within the field of automation technology in the 1980s, such as increasing loads, moving cables guided inside cable carriers often failed, although the cable carriers themselves did not. In extreme cases, failures caused by "corkscrews" and core ruptures brought entire production lines to a standstill, at high cost. As a result, specialized, highly flexible cables were developed with unique characteristics to differentiate them from standard designs. These are sometimes called "chain-suitable," "high-flex," or "continuous flex" cables.

A higher level of flexibility means the service life of a cable inside a cable carrier can be greatly extended. A normal cable typically manages 50,000 cycles, but a dynamic cable can complete between one and three million cycles.

6.1 Construction

Flexible cables can be divided into two types: those with conductors stranded in layers inside the cable, and those that have bundled or braided conductors.

Here the cable conductors are stranded into bundles

6.1.1 Stranding in layers

Stranding in layers is easier to produce, and therefore usually less expensive. The cable cores are stranded firmly and left relatively long in several layers around the center and are then enclosed in an extruded tube shaped jacket. In the case of shielded cables, the cores are wrapped up with fleece or foils.

However, this type of construction means that, during the bending process, the inner radius compresses and the outer radius stretches as the cable core moves. Initially, this works quite well, because the elasticity of the material is still sufficient, but material fatigue can set in and cause permanent deformations. The cores move and begin to make their own compressing and stretching zones, which can lead to a "corkscrew" shape, and ultimately, core rupture.

6.1.2 Stranding in bundles

The unique cable construction technique of braiding conductors around a tension-proof centre instead of layering them is the second type of construction.

Eliminating multi-layers guarantees a uniform bend radius across each conductor. At any point where the cable flexes, the path of any core moves quickly from the inside to the outside of the cable. The result is that no single core compresses near the inside of the bend or stretches near the outside of the bend—which reduces overall stresses. An outer jacket is still required to prevent the cores untwisting. A pressure filled jacket, rather than a simple extruded jacket, is preferable here. This fills all the gussets around the cores and ensures that the cores cannot untwist. The resulting dynamic cable is often stiffer than a standard cable, but lasts longer in applications where it must constantly flex.

6.2 References

- List of flexible cable suppliers
- Another list from the Kellysearch industrial directory

Chapter 7

Multicore cable

A *multicore cable* is a generic term for an electrical cable that has multiple cores made of copper wire. The term is normally only used in relation to a cable that has more cores than commonly encountered. For example, a four core mains cable is never referred to as multicore, but a cable comprising four coaxial cables in a single sheath would be considered multicore.

The term **snake cable** is frequently used in the professional audio recording industry to refer to an audio multicore cable.

Multicore cables are used with professional video cameras. In television studios, 26-pin cables are used to connect “cameras” to camera control units (CCU). Triaxial cables are used primarily in outside broadcasting however both are capable of delivering an HD-SDI feed and 30 - 40 Watts of power for the Cameras.

Many different kinds of multicore cable can be found in the list of video connectors.

Typical signals multicore cable can provide both digital signal and analog signals:

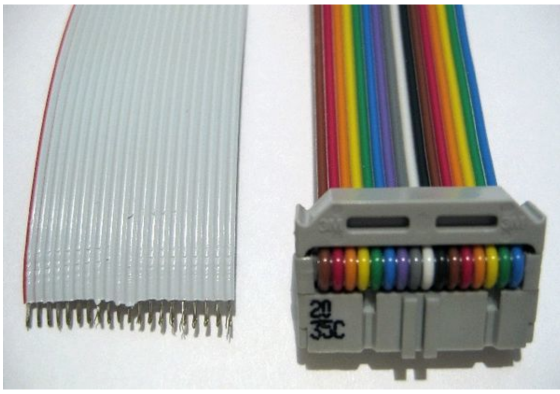
- Video out (Serial digital interface (SDI))
- Video out (composite video)
- Video out (component video)
- Audio out (microphone on board)
- Video in (genlock in the form of color burst)
- Return video in (composite)
- Return video in
- Interruptible feedback Intercom
- Tally light trigger

Chapter 8

Ribbon cable

For the 300-ohm antenna cable, see Twin-lead.

A **ribbon cable** (also known as multi-wire planar cable)



Left: 20-way grey ribbon cable with wire no. 1 marked red, insulation partly stripped. Right: 16-way rainbow ribbon with IDC connector.

is a cable with many conducting wires running parallel to each other on the same flat plane. As a result the cable is wide and flat. Its name comes from its resemblance to a piece of ribbon.[1]

Ribbon cables are usually seen for internal peripherals in computers, such as hard drives, CD drives and floppy drives. On some older computer systems (such as the BBC Micro and Apple II series) they were used for external connections as well. The ribbon-like shape interferes with computer cooling by disrupting airflow within the case and also makes the cables awkward to handle, especially when there are a lot of them; as a result, round cables have almost entirely replaced ribbon cables for external connections and are increasingly being used internally as well.

8.1 History

The ribbon cable was invented in 1956 by Cicoil Corporation, a company based in Chatsworth, California. The company's engineers figured out how to use a new material, silicone rubber, to 'mold' a flat cable containing multiple conductors of the same size. Since the cable looked like a flat ribbon or tape, it was named a ribbon cable. The ribbon cable allowed companies like IBM and Sperry/Univac to replace bulky, stiff round cables with sleek, flexible ribbon cables.

The early ribbon cables were used in the mainframe computer industry, on card readers, card punching machines, and tape machines. Subsequently ribbon cables were manufactured by a number of different companies, including 3M. Methods and materials were developed to simplify and reduce the cost of ribbon cables, by standardizing the design and spacing of the wires, and the thickness of the insulation, so that they could be easily terminated through the use of insulation displacement connectors (IDC). Due to the simplicity of ribbon cables, their low profile, and low cost due to standardization, ribbon cables are used today in most computers, printers, and many electronic devices.

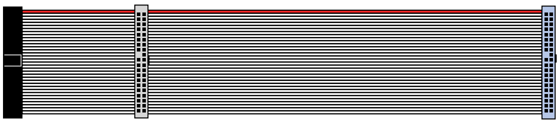
During the 1960s and 1970s the company provided flat cables for NASA and the US Government. In the 1990s Cicoil developed a unique extrusion process to make ribbon cables and flat flexible cables out of wires, hollow tubing, coaxial cable, and fiber optics. These cables are used in applications including missiles, satellites, semiconductor manufacturing equipment, and medical equipment.

8.2 Color-coding

To reduce the risk of reversed connections—which could potentially damage hardware—either when making a cable or when using a cable with unpolarized connectors, one edge of the cable is usually marked with a red stripe. By convention the edge with the stripe is connected to pin 1 on the connector. This method of identification is fine for cables that just consist of two or more IDC connectors with every connector connecting to every wire, but is somewhat less helpful when individual wires or small groups of wires must be terminated separately.

To make it easier to identify individual conductors in a cable; ribbon-cable manufacturers introduced rainbow ribbon cable, which uses a repeating pattern of colors borrowed from the standard resistor color code (Brown is pin 1 or pin 11 or pin 21, etc. Red is pin 2 or pin 12 or pin 22, etc.). It is often known affectionately to its users as "hippie cable" due to its distinct appearance. However, this has remained a specialized and relatively expensive product.

8.3 Sizes



Ribbon cable with three connectors

Ribbon cables are usually specified by two numbers: the spacing or *pitch* of the conductors, and the number of conductors or *ways*. A spacing of 0.05 inch (1.27 mm) is the most usual, allowing for a two-row connector with a pin spacing of 0.1 inch (2.54 mm). These types are used for many types of equipment, in particular for interconnections within an enclosure. For personal computers, this size is used today in floppy-disk-drive cables and older or custom Parallel ATA cables.

Based on availability of standard connectors, the number of conductors is usually restricted to a few values, These include 4, 6, 8, 9, 10, 14, 15, 16, 18, 20, 24, 25, 26, 34, 37, 40, 50, 60, 64 and 80. The wire is usually stranded copper wire, usually either 0.32, 0.20, or 0.13 mm^2 (22, 24, or 26 AWG).

Finer and coarser pitch cables are also available. For instance, the high-speed ATA interface cable used for computer hard disk interfaces ULTRA-ATA has 0.025-inch (0.64-mm) pitch. Finer pitches, as small as 0.3 mm, are found in portable electronic equipment, such as laptops; however, portable electronic equipment usually uses flexible flat cables (FFC).

8.4 Connectors

The main point of ribbon cables is to allow mass termination to specially designed IDC connectors in which the ribbon cable is forced onto a row of sharp forked contacts. (The phrase "IDC connector" is widely used, even though it is redundant—an example of RAS syndrome.) Most commonly termination is done at both ends of the cable, although sometimes (for example, when making a lead that needs to change wiring between the two connectors) only one end will be IDC terminated, with the other end being terminated in a regular crimp or solder-bucket connection. Although it is sometimes possible to dismantle and re-use IDC connectors, they are not designed to allow this to be done easily.

Popular types of connectors available with IDC termination suitable for ribbon cable include

- BT224 connector – also defined by BS9525-F0023, DIN41651, MIL-C-83503 standards; these are the type used on ATA cables and are often simply called "IDC connectors". They mate with either a purpose-made plug or a two-row grid of header pins with 0.1 inch (2.54 mm) spacing.
- D-subminiature connector – used for serial ports and printer ports (however IDC D connectors are far less common than crimp and solder bucket types).
- Micro ribbon connector - used for 36-pin printer ports (IEEE 1284 - "Centronics") and 50-pin SCSI ports.
- DIN 41612 connector – used for Eurocard buses.
- PCB transition headers – has two rows of pins with the same spacings as BT244 connectors. Intended to be soldered directly into a PCB.
- DIL headers – Has pins with the same spacings as standard DIL ICs. Generally used where for some reason it is desired to replace an IC with a connection to an external device (*e.g.,* in-circuit emulators). Can also be used like a PCB transition header, especially on stripboard. (Fitting a standard-spacing header to stripboard is tricky, because you have to cut the tracks between two holes rather than on a hole.)

When electronics hobbyists are working on their computers or digital musical keyboards to "mod" (modify) or "hack" them, they sometimes have to solder ribbon cables. Soldering ribbon cables can present a challenge to a hobbyist who has not been trained as an electronics technician. In some cases, hobbyists strip off the wire with a fine razor, and then separate the wires before soldering them. Some hobbyists use fine sandpaper to wear away the plastic insulation from the wires. The sanding also primes the copper tracks. Then when the "tinned" soldering iron is touched onto the bare wire, the solder is guided into the track.

8.4.1 Interference

From a digital point of view, ribbon cable is an ideal way to connect two devices. However, from an analog point of view, these cables are problematic. Around 1980, the U.S. Federal Communications Commission (FCC) discovered that ribbon cables were highly efficient antennas, broadcasting essentially random signals across a wide band of the electromagnetic spectrum. These unintended signals could interfere with domestic TV reception, putting "snow" on the screen. The FCC issued edicts and injunctions to the personal-computer industry, restricting the use of ribbon cables to connect devices together. "Naked" ribbon cable could be used inside the case of a computer or peripheral device, but any ribbon cable connecting two boxes together had to be grounded. This rule led to solutions such as ribbon cables covered by a copper-braid shield, which made it impossible to see or separate the individual connectors. On the Apple II, these cables passed through the holes on the back of the computer that were grounded to the power supply. Eventually, ribbon connectors were replaced, for inter-connect purposes, by a wide profusion of custom-designed round cables with molded connectors.

8.4.2 Impedance

One of the most popular sizes of ribbon cable employs 26AWG wire. Using the common 0.050” spacing and common PVC insulation the resultant impedance for any two adjacent wires within the cable is; Z = 110 - 130 (ohms).[2] The precise number will vary a few percent due to materials. Knowledge of the impedance is one step toward understanding and control of interference that may be caused by ribbon cables.

8.4.3 Proper Usage

According to NASA standards, the minimum bend radius for short term uses should be no less than 6 diameters, and no less than 10 diameters for long term use.[3]

8.5 See also

- Flexible flat cable (FFC)

8.6 References

[1] Hunter Cable Assembly Ltd. “Ribbon-and-Flat-Cable-Assemblies-whitepaper.pdf” (PDF). *white paper*. Hunter Cable Assembly.

[2] Digital Systems Engineering, William J. Dally, John W. Poulton, page 52 “2.7.2.2 Ribbon cable”

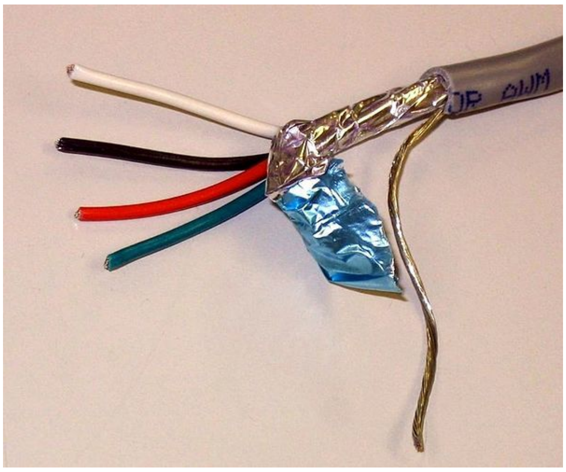
[3] Gregory, Frederick D. “NASA-STD 8739.4: Criming, Interconnecting Cables, Harnesses, and Wiring” (PDF). *hq.nasa.gov*. National Aeronautics and Space Administration. p. 36. Retrieved 5 December 2014.

- Product Design for Manufacture and Assembly, Third Edition page 143-144 “4.4 Types of wires and cables”
- Digital Systems Engineering, William J. Dally, John W. Poulton, page 52 “2.7.2.2 Ribbon cable”

Chapter 9

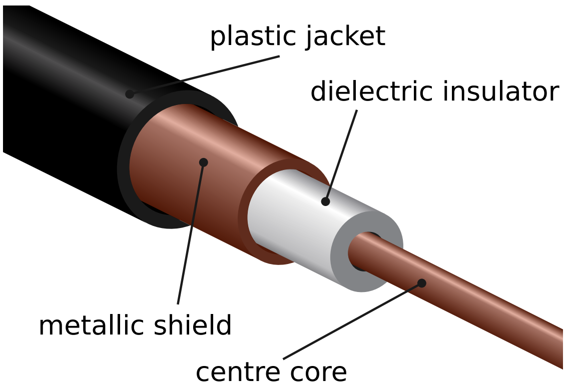
Shielded cable

[1]



Four-conductor shielded cable with metal foil shield and drain wire.

Electronic symbol for a shielded wire



Coaxial cable.

A **shielded** cable is an electrical cable of one or more insulated conductors enclosed by a common conductive layer. The shield may be composed of braided strands of copper (or other metal, such as aluminium), a non-braided spiral winding of copper tape, or a layer of conducting polymer. Usually this shield is covered with a jacket. The shield acts as a Faraday cage to reduce electrical noise from affecting the signals, and to reduce electromagnetic radiation that may interfere with other devices. (For more, see electromagnetic interference). The shield minimizes capacitively coupled noise from other electrical sources. The shield must be applied across cable splices.

In shielded signal cables the shield may act as the return path for the signal, or may act as screening only.

High voltage power cables with solid insulation are shielded to protect the cable insulation, people and equipment.

9.1 Signal cables

The common method to wire shielded cables is to ground only the source end of the shield to avoid ground loops. However, in airplanes special cable is used with both an outer shield to protect for lightning and an inner shield grounded at one end to eliminate hum from the 400 Hz power system.[2]

9.1.1 Applications

The use of shielded cables in security systems provides some protection from power frequency and radio frequency interference, reducing the number of false alarms being generated. The best practice is to keep data or signal cables physically separated by at least 3 inches (75mm) from 'heavy' power circuits which are in parallel.

Microphone or "signal" cable used in setting up PA and recording studios is usually shielded twisted pair cable, terminated in XLR connectors. The twisted pair carries the signal in a balanced audio configuration.

The cable laid from the stage to the mixer is often multicore cable carrying several pairs of conductors.

Consumer use screened copper wire with one central conductor in an unbalanced configuration.

Also see: High-end audio cables

9.2 Power cables

Medium and high-voltage power cables, in circuits over 2000 volts, usually have a shield layer of copper or aluminium tape or conducting polymer. If an unshielded insulated cable is in contact with earth or a grounded object, the electrostatic field around the conductor will be concentrated at the contact point, resulting in corona discharge, and eventual destruction of the insulation. Leakage current and capacitive current through the insulation presents a danger of electrical shock. The grounded shield equalizes electrical stress around the conductor, diverts any leakage current to ground. Stress relief cones should be applied at the shield ends, especially for cables operating at more than 2 kV to earth.

Shields on power cables may be connected to earth ground at each shield end and at splices for redundancy to prevent shock even though induced current will flow in the shield. This current will produce losses and heating and will reduce the maximum current rating of the circuit. Tests show that having a bare grounding conductor adjacent to the insulated wires will conduct the fault current to earth more quickly. On high-current circuits the shields might be connected only at one end. On very long high-voltage circuits, the shield may be broken into several sections since a long shield run may rise to dangerous voltages during a circuit fault. There is a risk of shock hazard from having only one end of the shield grounded. The maximum recommended shield potential rise is 25 volts. IEEE 422 and 525 lists the cable lengths that would limit shield potential to 25 volts for a single point ground application.[3][4][5]

9.3 References

[1] §

[2] "Aero 10 - Loop Resistance Tester". 090528 boeing.com

[3] Thomas P. Arnold; C. David Mercier (1997). *Southwire Company Power Cable Manual* (2 ed.). Carrollton, GA 30119: Southwire Company.

[4] IEEE 422: IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations

[5] IEEE 525: IEEE Guide for the Design and Installation of Cable Systems in Substations

9.4 External links

- Belden Corp article for *Broadcast Engineering* magazine
- Independent comparative study UTP vs. STP for 10GBase-T
- "Shielding". *Okonite Engineering Technical Center*. Okonite. Retrieved 4 October 2011.

Chapter 10

Submersible pump

A **submersible pump** (or **sub pump, electric submersible pump** (ESP)) is a device which has a hermetically sealed motor close-coupled to the pump body. The whole assembly is submerged in the fluid to be pumped.[4] The main advantage of this type of pump is that it prevents pump cavitation, a problem associated with a high elevation difference between pump and the fluid surface. Submersible pumps push fluid to the surface as opposed to jet pumps having to pull fluids. Submersibles are more efficient than jet pumps.

One style of submersible pump for industrial use. Outlet pipe and electrical cable not connected.

10.1 History

Ca. 1928 Russian oil delivery system engineer and inventor Armais Arutunoff successfully installed the first submersible oil pump.[1] In 1929, Pleuger Pumps pioneered the design of the submersible turbine pump, the forerunner of the modern multi-stage submersible pump.[2] In the mid 1960s the first fully submersible deep-well water pump was developed.[3]

10.2 Working principle

The submersible pumps used in ESP installations are multistage centrifugal pumps operating in a vertical position. Although their constructional and operational features underwent a continuous evolution over the years, their basic operational principle remained the same. Produced liquids, after being subjected to great centrifugal forces caused by the high rotational speed of the impeller, lose their kinetic energy in the diffuser where a conversion of kinetic to pressure energy takes place. This is the main operational mechanism of radial and mixed flow pumps.

The pump shaft is connected to the gas separator or the protector by a mechanical coupling at the bottom of the pump. When fluids enter the pump through an intake screen and are lifted by the pump stages.Other parts include the radial bearings (bushings) distributed along the length of the shaft providing radial support to the pump shaft turning at high rotational speeds. An optional thrust bearing takes up part of the axial forces arising in the pump but most of those forces are absorbed by the protector's thrust bearing.

10.3 Applications

Submersible pumps are found in many applications. Single stage pumps are used for drainage, sewage pumping, general industrial pumping and slurry pumping. They are also popular with pond filters. Multiple stage submersible pumps are typically lowered down a borehole and most typically used for residential, commercial, municipal and industrial water extraction (abstraction), water wells and in oil wells.

Other uses for submersible pumps include sewage treatment plants, seawater handling, fire fighting (since it is flame retardant cable), water well and deep well drilling, offshore drilling rigs, artificial lifts, mine dewatering, and irrigation systems.

Special attention to the type of submersible pump is required when using certain types of liquids. Pumps used for combustible liquids or for water that may be contaminated with combustible liquids must be designed not to ignite the liquid or vapors.

10.4 Use in oil wells

Submersible pumps are used in oil production to provide a relatively efficient form of "artificial lift", able to operate across a broad range of flow rates and depths.[4][5] By decreasing the pressure at the bottom of the well (by lowering bottomhole flowing pressure, or increasing drawdown), significantly more oil can be produced from the well when compared with natural production. The pumps are typically electrically powered and referred to as Electrical Submersible Pumps (ESP).

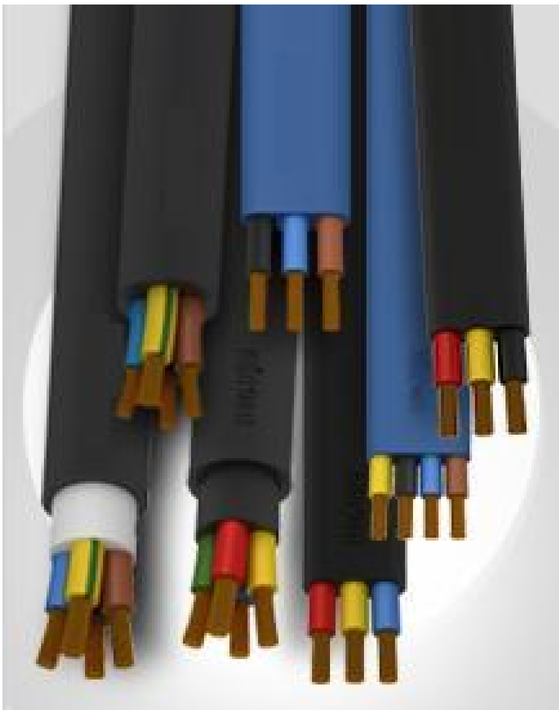
ESP systems consist of both surface components (housed in the production facility, for example an oil platform) and sub-surface components (found in the well hole). Surface components include the motor controller (often a variable speed controller), surface cables and transformers. Subsurface components typically include the pump, motor, seal and cables. A gas separator is sometimes installed.[4]

The pump itself is a multi-stage unit with the number of stages being determined by the operating requirements. Each stage consists of a driven impeller and a diffuser which directs flow to the next stage of the pump. Pumps come in diameters from 90mm (3.5 inches) to 254mm (10 inches) and vary between 1 metre (3 ft) and 8.7 metres (29 ft) in length. The motor used to drive the pump is typically a three phase, squirrel cage induction motor, with a nameplate power rating in the range 7.5 kW to 560 kW (at 60 Hz).[4]

New varieties of ESP can include a water/oil separator which permits the water to be reinjected into the reservoir without the need to lift it to the surface. There are at least 15 brands of oilfield esps used throughout the world. Until recently, ESPs had been highly costly to install due to the requirement of an electric cable downhole. This cable had to be wrapped around jointed tubing and connected at each joint. New coiled tubing umbilicals allow for both the piping and electric cable to be deployed with a single conventional coiled tubing unit.

The ESP system consists of a number of components that turn a staged series of centrifugal pumps to increase the pressure of the well fluid and push it to the surface. The energy to turn the pump comes from a high-voltage (3 to 5 kV) alternating-current source to drive a special motor that can work at high temperatures of up to 300 °F (149 °C) and high pressures of up to 5,000 psi (34 MPa), from deep wells of up to 12,000 feet (3.7 km) deep with high energy requirements of up to about 1000 horsepower (750 kW). ESPs have dramatically lower efficiencies with significant fractions of gas, greater than about 10% volume at the pump intake. Given their high rotational speed of up to 4000 rpm (67 Hz) and tight clearances, they are not very tolerant of solids such as sand.

10.5 Cables



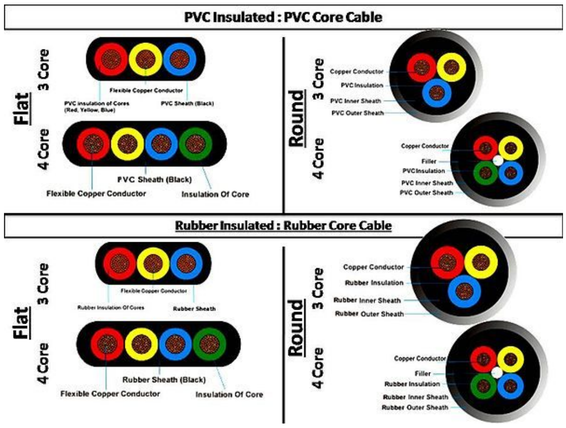
Submersible Pump Cables: 3&4 Core Round and Flat Cables in PVC and Rubber Insulation

Submersible pump cable are designed for use in wet ground or under water, with types specialized for pump environmental conditions.[6][7][8]

A submersible pump cable is a specialized product to be used for a submersible pump in a deep well, or in similarly harsh conditions. The cable needed for this type of application must be durable and reliable as the installation location and environment can be extremely restrictive as well as hostile. As such, submersible pump cable can be used in both fresh and salt water. It is also suitable for direct burial and within well castings. A submersible pump cable's area of installation is physically restrictive. Cable manufacturers must keep these factors in mind to achieve the highest possible degree of reliability. The size and shape of submersible pump cable can vary depending on the usage and preference and pumping instrument of the installer. Pump cables are made in single and multiple conductor types and may be flat or round in cross section; some types include control wires as well as power conductors for the pump motor. Conductors are often color-coded for identification and an overall cable jacket may also be color-coded.

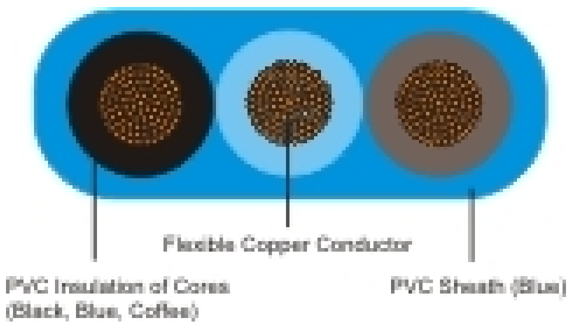
Major types of cable include:

In 3&4 Core cable as per right side *SPC types* image shown, Plain Copper/Tinned Copper used as conductor.



Different types of SPC

- PVC 3&4 Core Cable
  - Flat Cable
  - Round Cable
- Rubber 3&4 Core Cable
  - Flat Cable
  - Round Cable
- Flat Drincable
- HO7RN-F Cable



DRINCABLE Diagram

10.6 See also

- Centrifugal pump
- Eductor-jet pump
- Oil well
- Sewage pumping
- Booster pump

10.7 References

[1] A Historical Perspective of Oilfield Electrical Submersible Pumps

[2] World Pumps: A Brief History of Pumps

[3] Grundfoss Museum- Youtube

[4] Lyons (ed), *Standard Handbook of Petroleum & Natural Gas Engineering", p. 662*

[5] Other forms of artificial lift include Gas Lift, Beam Pumping, Plunger Lift and Progressive cavity pump.

[6] "Submersible pump cable", *The Pump Book*, pp. 67–74, ISBN 978-0-615-18509-5

[7] Ray C. Mullin, Phil Simmons (2011), "Submersible Pump Cable", *Electrical Wiring Residential*, pp. 423–424, ISBN 978-1-4354-9826-6

[8] Robert J. Alonzo (19 January 2010). *Electrical Codes, Standards, Recommended Practices and Regulations: An Examination of Relevant Safety Considerations*. Elsevier. pp. 317–. ISBN 978-0-8155-2045-0. Retrieved 16 November 2012.

- Lyons, William C., ed. (1996). *Standard Handbook of Petroleum & Natural Gas Engineering* **2** (6 ed.). Gulf Professional Publishing. ISBN 0-88415-643-5.

10.8 External links

- Water well pump article
- *Versatile Pump Works Under Water*, July 1947, Popular Science excellent cutaway drawing of large public water works submersible pump design

Chapter 11

Twinaxial cabling

Twinaxial plug

Twinaxial cabling, or **"Twinax"**, is a type of cable similar to coaxial cable, but with two inner conductors instead of one. Due to cost efficiency it is becoming common in modern (2013) very-short-range high-speed differential signaling applications.

11.1 Legacy applications

11.1.1 IBM

Historically, Twinax was the cable specified for the IBM 5250 terminals and printers, used with IBM's midrange hosts, iSeries, (currently Power systems hardware running IBM's 'i' operating system i5/OS), and also with its predecessors, such as the S/32, S/34, S/36, S/38 and AS/400 (Application System 400) minicomputers. The data transmission is half-duplex, balanced transmission, at 1 Mbit/s, on a single shielded, 110 Ω twisted pair.[1]

With Twinax seven devices can be addressed, from workstation address 0 to 6. The devices do not have to be sequential.

Twinax is a bus topology that requires termination to function properly. Most Twinax T-connectors have an automatic termination feature. For use in buildings wired with Category 3 or higher twisted pair there are baluns that convert Twinax to twisted pair and hubs that convert from a bus topology to a star topology.

Twinax was designed by IBM. Its main advantages were high speed (1 Mbit/s versus 9600 bit/s) and multiple addressable devices per connection. The main disadvantage was the requirement for proprietary Twinax cabling with bulky screw-shell connectors.

Physical layer

Signals are sent differentially over the wires at 1 Mbit/s (1 µs/bit, ±2 %), Manchester coded, with preemphasis.[2] The signal coding is only approximately differential and not completely differentially balanced. In general, one of the two signal lines is driven to −0.32 V (±20 %), while the other carries 0 V. This, itself, could be considered as two differential signals of ±0.16 V superimposed on a −0.16 V common mode level. However, to provide preemphasis, for the first 250 ns (1/4 bit time) after a signal is driven low, the negative signal line is driven to −1.6 V. During this time, the common-mode voltage is −0.8 V.

This signal is designed to provide a minimum of ±100 mV at the end of 152m (500 feet) of cable.

The two wires are denoted A and B. To encode a 0 bit, A>B for the first half of the bit time, and A<B for the second half. A 1 bit is the opposite. Thus, each signal line is driven low for either 500 or 1000 ns at a time, of which the first 250 ns is emphasized.

Data link layer

A message begins with five normal 1 bits (A driven low for 500 ns, then B driven low for 500 ns) for bit synchronization, followed by a special frame sync pattern, three bit times long, that violates the usual Manchester encoding rules. A is driven low for 1500 ns, then B is driven low for 1500 ns. This is like a 1 bit sent at 1/3 normal speed (although the premphasis pulses remain 250 ns long).[2][3]

This pattern is followed by up to 256 16-bit data frames. Each data frame consists of a start bit of 1, an 8-bit data field, a 3-bit station address, and an even parity bit (which includes the start bit, so it equivalent to odd parity over the data and address fields only). This is then followed by three or more fill bits of 0. Unusually for an IBM protocol, the bits within each frame are sent lsbit-first.[3]

All messages are sent between the controller (master) and one slave device. The first frame in a message from the controller contains the device's address, from 0 to 6. The address field of following frames can be any value from 0 to 6, although is usually set to the device's address as well. The final frame in a message includes an address of 7 (all ones) as an end-of-message (EOM) indicator. A single-frame message does not have an EOM indicator.

When a command calls for a response, the device is expected to respond in 30 to 80 µs. A device's response also consists of up to 256 frames, and includes its address in all frames but the last. In this case, a single-frame response includes the EOM address, and the controller assumes it comes from the device it most recently addressed.

Generally, the first frame in a message is a command byte, and following frames are associated data.[3][4]

11.1.2 NEC

NEC Astra system also uses this kind of cable for networking.

11.1.3 MIL-STD-1553

MIL-STD-1553 specifies that the data bus should have characteristic impedance between 70 and 85 ohms and industry has standardized on 78 ohms. Likewise, the industry has generally standardized on the cable known as Twinax cable that has a characteristic impedance of 78 ohms.

11.2 Current applications

11.2.1 SFP+ Direct-Attach Copper (10GSFP+Cu)

This is a copper 10 Gigabit Ethernet cable which comes in either an active or passive Twinax (twinaxial) cable assembly and connects directly into an SFP+ housing. The active Twinax cable has active electronic components in the SFP+ housing to improve the signal quality; the passive Twinax cable is just a straight "wire" and contains no active components. Generally Twinax cables less than 5 meters in length are passive and greater than 5 meters in length are active, but this is a general rule of thumb and will vary from vendor to vendor. SFP+ Direct Attach Copper (DAC) is expected to be the optimum solution for 10G Ethernet reaches up to 10 m.[5]

One of major applications includes Brocade, Arista, Cisco and others' network hardware with SFP+ interfaces. This type of connection is able to transmit at 10 Gigabits/second full duplex speed over 5 meter distances. Moreover, this setup offers 15 to 25 times lower transceiver latency than current 10GBASE-T Cat 6/Cat 6a/Cat 7 cabling systems: 0.1 µs for Twinax with SFP+ versus 1.5 to 2.5 µs for current 10GBASE-T specification. The power draw of Twinax with SFP+ is around 0.1 watts, which is also much better than 4–8 watts for 10GBASE-T.

As always with cabling one of the consideration points is bit error ratio or BER for short. Twinax copper cabling has BER better than 10^{-18} according to Cisco, and therefore is acceptable for applications in critical environments.

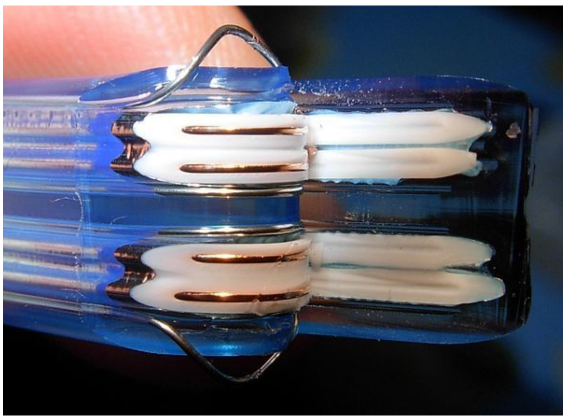
Cables must not be bent below their minimum bend radius,[6][7] which is depending on cable size expressed in AWG. The table on the right summarizes minimum values typically admitted for SFP+ sustained bend radiuses.

This SFP+ Twinax DAC is also referred to as "10GBASE-CR" by some manufacturers,[8] even though there is no IEEE or other standard with that name.

11.2.2 100 Gbit Ethernet

40GBASE-CR4 and 100GBASE-CR10 physical layers using 7 m twin-axial cable are being developed as part of 100 Gbit Ethernet specifications by IEEE 802.3bj workgroup.

11.2.3 SATA 3.0 cables



Cross section of a SATA 3.0 cable, showing the dual Twinax conductors for the differential pairs.

SATA 3.0 cables are implemented using Twinax (twinaxial cable).

11.2.4 DisplayPort

Many manufacturers of DisplayPort cabling are also using Twinax configurations to accommodate the strict insertion loss, return loss, and crosstalk requirements for the 2.7 Gbit/s signaling rate.

11.2.5 MIL-STD-1553

The cable used to connect the MIL-STD-1553 bus and stub devices has a characteristic impedance of 78 ohms at 1 MHz. A 2-conductor twisted-pair cable known as Twinax is used to connect the bus and stub devices. The insulated pairs are balanced and have an overall shielding braid around the pairs. The twisting of the signal-carrying pairs theoretically cancels any random induced noise caused by the pair. The two internal dielectric fillers separate the braid from the pairs to minimize the leakage capacitance to ground. The fillers also assist in uniform twisting of the pairs. The 90% braid coverage protects the pair from external noise. PVC outer jacket cable is suitable for lab use while high-temperature rated outer jacket cable is applicable for vehicle use.

11.3 See also

- Coaxial cable
- IBM 5250
- Triaxial cable

11.4 References

[1] "NLynx Technologies - what is Twinax?". NLynx. 2006.

[2] Quigley, Thomas J. (March 1988), *Interfacing the DP8344 to Twinax* (PDF), National Semiconductor, AN-516

[3] *Twinax Cable Information*, Anzac Computer Equipment Corporation, 2004-07-22, retrieved 2009-01-30

[4] Norcross, Thomas; Patchen, Paul J.; Quigley, Thomas J.; Short, Tim; Worsley, Debra; Johnson, Laura (April 1995), *MPA-II—A Multi-Protocol Terminal Emulation Adapter Using the DP8344* (PDF), National Semiconductor, AN-641

[5] "10 gigabit Ethernet - alphabet soup never tasted so good". Archived from the original on 2009-08-16. Retrieved 2009-08-13.

[6] "Recommended minimum bend radii for QSFP+ and SFP+ cables". Retrieved 2014-04-24.

[7] "Temporary and Sustained Bend Radii for GORE™ SFP+ cables" (PDF). Retrieved 2014-04-24.

[8] "Arista Networks Transceivers & Cables". Retrieved 2012-03-28.

11.5 External links

- Cisco 10GBASE SFP+ Modules
- MIL-STD-1553B Concepts and Considerations from MilesTek Corporation

Chapter 12

Twin-lead

300 ohm twin-lead

Twin-lead cable is a two-conductor flat cable used as a transmission line to carry radio frequency (RF) signals. It is constructed of two multistranded copper or copper-clad steel wires, held a precise distance apart by a plastic (usually polyethylene) ribbon. The uniform spacing of the wires is the key to the cable's function as a parallel transmission line; any abrupt changes in spacing would reflect radio frequency power back toward the source. The plastic also covers and insulates the wires. In 300 ohm twin-lead, the most common type, the wire is usually 20 or 22 gauge, about 7.5 mm (0.30 inches) apart.[1]

12.1 Characteristics and uses

Twin lead and other types of parallel-conductor transmission line are mainly used to connect radio transmitters and receivers to their antennas. Parallel transmission line has the advantage that its losses are an order of magnitude smaller than coaxial cable, the main alternative form of transmission line. Its disadvantages are that it is more vulnerable to interference, and must be kept away from metal objects which can cause power losses. For this reason, when installed along the outside of buildings and on antenna masts, standoff insulators must be used. It is also common practice to twist the twin lead on long free standing lengths to further reject any induced imbalances to the line.

Twin-lead is supplied in several different sizes, with values of 600, 450, 300, and 75 ohms characteristic impedance. The most common, 300 ohm twin-lead, was once widely used to connect television sets and FM radios to their receiving antennas. 300 ohm twin-lead for television installations has been largely replaced with 75 ohm coaxial cable feedlines. Twin-lead is also used in amateur radio stations as a transmission line for balanced transmission of radio frequency signals.

12.2 How it works

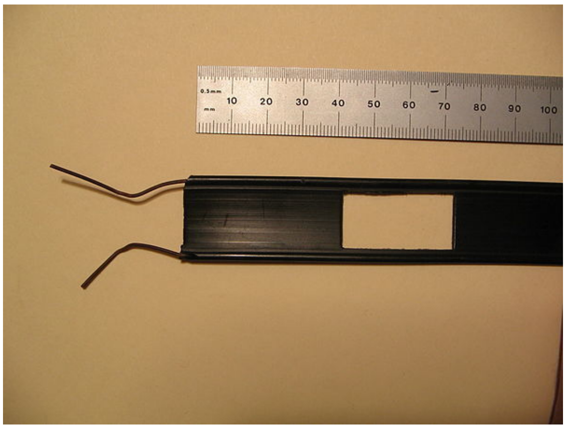
A 300-to-75-ohm balun, showing twin-lead on the right hand side

Twin lead is a form of parallel-wire balanced transmission line. The separation between the two wires in twin-lead is small compared to the wavelength of the radio frequency (RF) signal carried on the wire.[2] The RF current in one wire is equal in magnitude and opposite in direction to the RF current in the other wire. Therefore in the far field region far from the transmission line, the radio waves radiated by one wire are equal in magnitude but opposite in phase (180° out of phase) to the waves radiated by the other wire, so they superpose and cancel each other.[2] The result is that almost no net radio energy is radiated by the line.

Similarly, any interfering external radio waves will induce equal, in phase RF currents, traveling in the same direction, in the two wires. Since the load at the destination end is connected *across* the wires, only *differential*, oppositely-directed currents in the wires create a current in the load. Thus the interfering currents are canceled out, so twin lead does not tend to pick up radio noise.

However, if a piece of metal is located sufficiently close to a twin-lead line, within a distance comparable to the wire spacing, it will be significantly closer to one wire than the other. As a result the RF current induced in the metal object by one wire will be greater than the opposing current induced by the other wire, so the currents will no longer cancel. Thus nearby metal objects can cause power losses in twin lead lines, through energy dissipated as heat by induced currents. Similarly, radio noise originating in cables or metal objects located near the twin-lead line can induce unbalanced currents in the wires, coupling noise into the line.

12.3 Ladder line



450 ohm "Ladder line"

Ladder line or "window line" is a variation of twin lead which is constructed similarly except that the polyethylene webbing between the wires which holds them apart has rectangular openings ("windows") cut in it.[1]<ref "name="QST2">Ford, Steve (December 1993). "The Lure Of Ladder Line" (PDF). *QST* (ARRL). Retrieved September 16, 2011.</ref> So the line consists of two insulated wires with bands of plastic holding them together every few inches, giving it the appearance of a ladder. The advantage of the windows is that they lighten the line, and also reduce the amount of surface on which dirt and moisture can accumulate, making ladder line less vulnerable to weather-induced changes in characteristic impedance.[1] The most common type is 450 ohm ladder line, which has a conductor spacing of about an inch.[1]

Ladder line may also be manufactured or DIY-constructed as "open wire line" consisting of two parallel wires featuring widely spaced plastic or ceramic insulating bars and having a characteristic impedance of 600 ohms or more.[3]

12.4 Impedance matching

Main article: Impedance matching

As a transmission line, transmission efficiency will be maximum when the impedance of the antenna, the

600 ohm "Ladder line" on the outside of a building.

characteristic impedance of the twin-lead line and the impedance of the equipment are the same. For this reason, when attaching a twin-lead line to a coaxial cable connection, such as the 300 ohm twin-lead from a domestic television antenna to the television's 75 ohm coax antenna input, a balun with a 4:1 ratio is commonly used. Its purpose is double: first, it transforms twin-lead's 300 ohm impedance to match the 75 ohm coaxial cable impedance; and second, it transforms the balanced, symmetric transmission line to the unbalanced coax input. In general, when used as a feedline, twin-lead (especially ladder line versions) has a higher efficiency than coaxial cable when there is an impedance mismatch between the feedline and the source (or sink). For receive-only use this merely implies that the system can communicate under slightly less optimal conditions; for transmit use, this can often result in significantly less energy lost as heat in the transmission line.

Twin-lead also can serve as a convenient material with which to build a simple folded dipole antenna. Such antennas may be fed either by using a 300 ohm twin-lead feeder or by using a 300-to-75-ohm balun and using coaxial feedline and will usually handle moderate power loads without overheating.

12.5 Characteristic impedance

The characteristic impedance of a parallel-wire transmission line like twin lead or ladder line depends on its dimensions; the diameter of the wires *d* and their separation *D*. This is derived below.

The characteristic impedance of any transmission line is given by

$$Z = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$$

where for twin-lead line the primary line constants are

$$R = 2\frac{R_s}{\pi d}$$

$$L = \frac{\mu}{\pi}\ \text{arccosh}\left(\frac{D}{d}\right)$$

$G = \frac{\pi\sigma}{\text{arccosh}(\frac{D}{d})}$

$C = \frac{\pi\epsilon}{\text{arccosh}(\frac{D}{d})}$

where the surface resistance of the wires is

$R_s = \sqrt{\pi f \mu_c / \sigma_c}$

and where d is the wire diameter and D is the separation of the wires measured between their centrelines.

Neglecting the wire resistance R and the leakage conductance G, this gives

$$Z = \frac{Z_0}{\pi\sqrt{\epsilon_r}} \text{ arccosh}\left(\frac{D}{d}\right)$$ [4]

where Z_0 is the impedance of free space (approximately 377 Ω), εr is the effective dielectric constant (which for air is 1.00054). If the separation D is much greater than the wire diameter d then this is approximately

$$Z \approx 276 \log_{10}\left(2\frac{D}{d}\right)$$ [5]

The separation needed to achieve a given characteristic impedance is therefore

$$D = d \cosh\left(\pi \frac{Z\sqrt{\epsilon_r}}{Z_0}\right)$$

12.6 Antennas

Twin-lead can be connected directly to a suitably designed antenna:

- a dipole (whose impedance at resonance is approximately 73 ohms in free space),
- a folded dipole (a better match, since its characteristic impedance in free space is around 300 ohms),
- a Yagi antenna or similar balanced antenna.

12.7 References

[1] Straw, R. Dean, Ed. (2000). *The ARRL Antenna Book, 19th Ed.* USA: American Radio Relay League. pp. 24.16–17. ISBN 0-87259-817-9.

[2] Straw, R. Dean, Ed. (2000). *The ARRL Antenna Book, 19th Ed.* USA: American Radio Relay League. p. 24.1. ISBN 0-87259-817-9.

[3] Danzer, Paul (April 2004). "Open Wire Feed Line— A Second Look". *QST* (ARRL). Retrieved September 16, 2011.

[4] Balanced Transmission Line in Current Amateur Practice, ARRL Antenna Compendium, Volume 6. Wes Stewart, N7WS.

[5] ARRL Handbook for Amateur Radio 2000, Pg 19.3.

Chapter 13

Twisted pair

25-pair color code *Chart*

Twisted pair cabling is a type of wiring in which two conductors of a single circuit are twisted together for the purposes of canceling out electromagnetic interference (EMI) from external sources; for instance, electromagnetic radiation from unshielded twisted pair (UTP) cables, and crosstalk between neighboring pairs. It was invented by Alexander Graham Bell.

13.1 Explanation

In balanced pair operation, the two wires carry equal and opposite signals and the destination detects the difference between the two. This is known as differential mode transmission. Noise sources introduce signals into the wires by coupling of electric or magnetic fields and tend to couple to both wires equally. The noise thus produces a common-mode signal which is canceled at the receiver when the difference signal is taken.

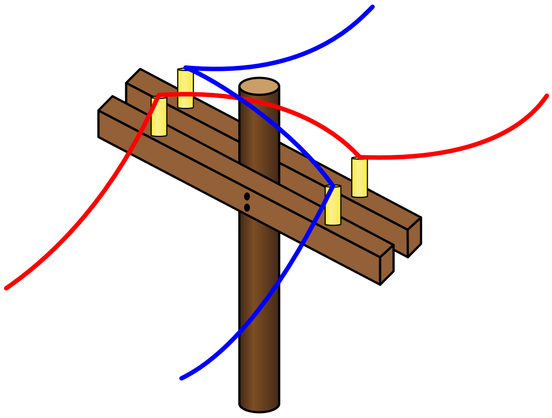
This method starts to fail when the noise source is close to the signal wires; the closer wire will couple with the noise more strongly and the common-mode rejection of the receiver will fail to eliminate it. This problem is especially apparent in telecommunication cables where pairs in the same cable lie next to each other for many miles. One pair can induce crosstalk in another and it is additive along the length of the cable. Twisting the pairs counters this effect as on each half twist the wire nearest to the noise-source is exchanged.

Providing the interfering source remains uniform, or nearly so, over the distance of a single twist, the induced noise will remain common-mode. Differential signaling also reduces electromagnetic radiation from the cable, along with the associated attenuation allowing for greater distance between exchanges.

The twist rate (also called *pitch* of the twist, usually defined in twists per meter) makes up part of the specification for a given type of cable. When nearby pairs have equal twist rates, the same conductors of the different pairs may repeatedly lie next to each other, partially undoing the benefits of differential mode. For this reason it is commonly specified that, at least for cables containing small numbers of pairs, the twist rates must differ.[1]

In contrast to **ScTP** (screened twisted pair), **STP** (shielded twisted pair), **FTP** (foiled twisted pair) and other shielded cabling variations, **UTP** (unshielded twisted pair) cable is not surrounded by any shielding. It is the primary wire type for telephone usage and is very common for computer networking, especially as patch cables or temporary network connections due to the high flexibility of the cables.

13.2 History



Wire transposition on top of pole

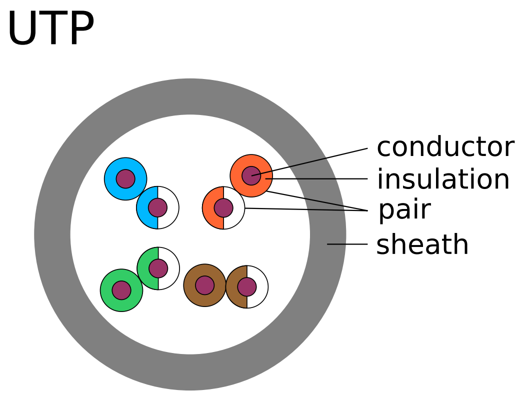
The earliest telephones used telegraph lines, or open-wire single-wire earth return circuits. In the 1880s electric trams were installed in many cities, which induced noise into these circuits. Lawsuits being unavailing, the telephone companies converted to balanced circuits, which had the incidental benefit of reducing attenuation, hence increasing range.

As electrical power distribution became more commonplace, this measure proved inadequate. Two wires, strung on either side of cross bars on utility poles, shared the route with electrical power lines. Within a few years, the growing use of electricity again brought an increase of interference, so engineers devised a method called wire transposition, to cancel out the interference.

In wire transposition, the wires exchange position once every several poles. In this way, the two wires would receive similar EMI from power lines. This represented an early implementation of twisting, with a twist rate of about four twists per kilometre, or six per mile. Such open-wire balanced lines with periodic transpositions still survive today in some rural areas.

Twisted pair cables were invented by Alexander Graham Bell in 1881.[2] By 1900, the entire American telephone line network was either twisted pair or open wire with transposition to guard against interference. Today, most of the millions of kilometres of twisted pairs in the world are outdoor landlines, owned by telephone companies, used for voice service, and only handled or even seen by telephone workers.

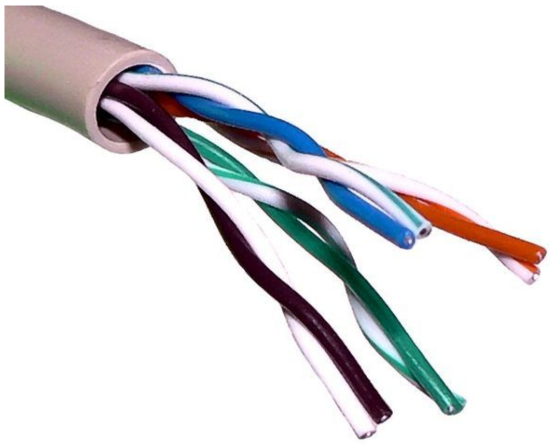
13.3 Unshielded twisted pair (UTP)



Unshielded twisted pair

UTP cables are found in many Ethernet networks and telephone systems. For indoor telephone applications, UTP is often grouped into sets of 25 pairs according to a standard 25-pair color code originally developed by AT&T Corporation. A typical subset of these colors (white/blue, blue/white, white/orange, orange/white) shows up in most UTP cables. The cables are typically made with copper wires measured at 22 or 24 American Wire Gauge (AWG),[3] with the colored insulation typically made from an insulator such as polyethylene or FEP and the total package covered in a polyethylene jacket.

For urban outdoor telephone cables containing hundreds or thousands of pairs, the cable is divided into smaller but identical bundles. Each bundle consists of twisted pairs that have different twist rates. The bundles are in turn twisted together to make up the cable. Pairs having the same twist rate within the cable can still experience some degree of crosstalk. Wire pairs are selected carefully to minimize crosstalk within a large cable.



Unshielded twisted pair cable with different twist rates

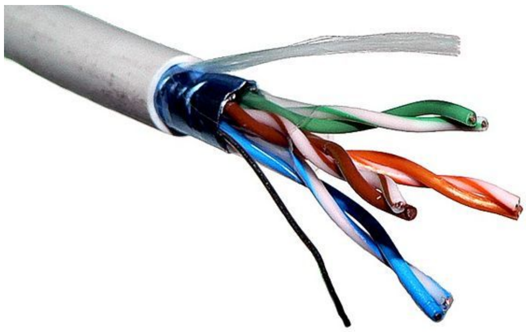
UTP cable is also the most common cable used in computer networking. Modern Ethernet, the most common data networking standard, can use UTP cables. Twisted pair cabling is often used in data networks for short and medium length connections because of its relatively lower costs compared to optical fiber and coaxial cable.

UTP is also finding increasing use in video applications, primarily in security cameras. Many cameras include a UTP output with screw terminals; UTP cable bandwidth has improved to match the baseband of television signals. As UTP is a balanced transmission line, a balun is needed to connect to unbalanced equipment, for example any using BNC connectors and designed for coaxial cable.

13.4 Cable shielding

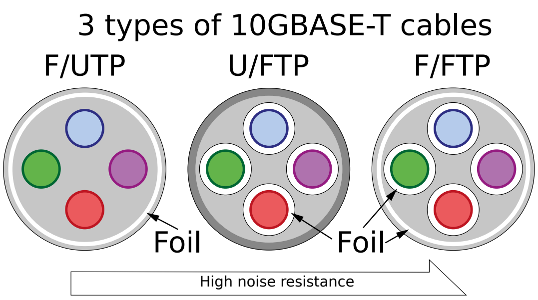
Main article: Electromagnetic shielding

Twisted pair cables are often shielded in an attempt to prevent electromagnetic interference. Shielding provides an electric conductive barrier to attenuate electromagnetic waves external to the shield and provides conduction path by which induced currents can be circulated and returned to the source, via ground reference connection.

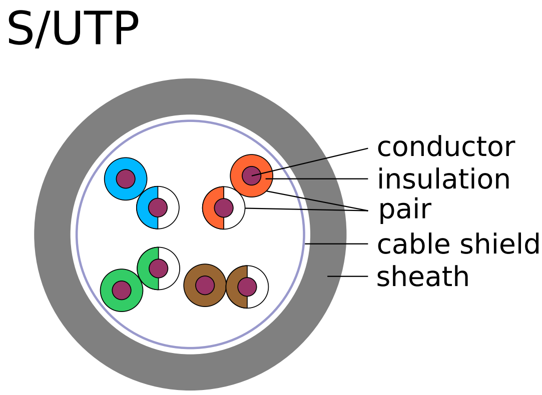


F/UTP cable

S/FTP cable



U/FTP, F/UTP and F/FTP are used in Cat.6a cables



S/UTP cable

This shielding can be applied to individual pairs or quads, or to the collection of pairs. Individual pairs are foiled, while overall cable may use braided screen, foil, or braiding with foil.

ISO/IEC 11801:2002 (Annex E) attempts to internationally standardise the various designations for shielded cables by using combinations of three letters - U for unshielded, S for braided shielding, and F for foiled shielding - to explicitly indicate the type of screen for overall cable protection and for individual pairs or quads, using a two-part abbreviation in the form of *xx/xTP*.

When shielding is applied to the collection of pairs, this is usually referred to as screening, however different vendors and authors use different terminology, employing "screening" and "shielding" interchangeably; for example, STP (shielded twisted pair) or ScTP (screened twisted pair) has been used to denote U/FTP, S/UTP, F/UTP, SF/UTP and S/FTP construction.[4]

Because the shielding is made of metal, it may also serve as a ground. Usually a shielded or a screened twisted pair cable has a special grounding wire added called a drain wire which is electrically connected to the shield or screen. The drain wire simplifies connection to ground at the connectors.

An early example of shielded twisted-pair is IBM STP-A, which was a two-pair 150 ohm S/FTP cable defined in 1985 by the IBM Cabling System specifications, and used with token ring or FDDI networks.[4][5]

Common shielded cable types used by Cat. 6a, Cat.7 and Cat.8 cables include:

Shielded twisted pair (U/FTP) Also pair in metal foil. Individual shielding with foil for each twisted pair or quad. This type of shielding protects cable from external EMI entering or exiting the cable and also protects neighboring pairs from crosstalk.

Screened twisted pair (F/UTP, S/UTP and SF/UTP) Also foiled twisted pair for F/UTP. Overall foil, braided shield or braiding with foil across all of the pairs within the 100 Ohm twisted pair cable. This type of shielding protects EMI from entering or exiting the cable.

Screened shielded twisted pair (F/FTP and S/FTP) Also fully shielded twisted pair, shielded screened twisted pair, screened foiled twisted pair, shielded foiled twisted pair. Individual shielding using foil between the twisted pair sets, and also an outer metal and/or foil shielding within the 100 Ohm twisted pair cable.[6] This type of shielding protects EMI from entering or exiting the cable and also protects neighboring pairs from crosstalk.

The code before the slash designates the shielding for the cable itself, while the code after the slash determines the shielding for the individual pairs:

U = unshielded

F = foil shielding

S = braided shielding (outer layer only)

TP = twisted pair

TQ = twisted pair, individual shielding in quads

13.5 Most common twisted-pair cables

See also: ISO/IEC 11801

13.6 Solid core cable vs stranded cable

A solid core cable uses one solid wire per conductor and in a four pair cable there would be a total of eight solid wires.[8] Stranded conductor uses multiple wires wrapped around each other in each conductor and in a four pair with seven strands per conductor cable, there would be a total of 56 wires (2 per pair x 4 pairs x 7 strands).[8]

Solid core cable is intended for permanently installed runs. It is less flexible than stranded cable and is more prone to failure if repeatedly flexed. Stranded cable is used for fly leads at patch panel and for connections from wall-ports to end devices, as it resists cracking of the conductors.

Connectors need to be designed differently for solid core than for stranded. Use of a connector with the wrong cable type is likely to lead to unreliable cabling. Plugs designed for solid and stranded core are readily available, and some vendors even offer plugs designed for use with both types. The punch-down blocks on patch-panel and wall port jacks are designed for use with solid core cable.

13.7 Advantages

- It is a thin, flexible cable that is easy to string between walls.
- More lines can be run through the same wiring ducts.
- Electrical noise going into or coming from the cable can be prevented.[9]
- Cross-talk is minimized.[9]

13.8 Disadvantages

- Twisted pair's susceptibility to electromagnetic interference greatly depends on the pair twisting schemes (usually patented by the manufacturers) staying intact during the installation. As a result, twisted pair cables usually have stringent requirements for maximum pulling tension as well as minimum bend radius. This relative fragility of twisted pair cables makes the installation practices an important part of ensuring the cable's performance.
- In video applications that send information across multiple parallel signal wires, twisted pair cabling can introduce signaling delays known as skew which cause subtle color defects and ghosting due to the image components not aligning correctly when recombined in the display device. The skew occurs because twisted pairs within the same cable often use a different number of twists per meter in order to prevent crosstalk between pairs with identical numbers of twists. The skew can be compensated by varying the length of pairs in the termination box, in order to introduce delay lines that take up the slack between shorter and longer pairs, though the precise lengths required are difficult to calculate and vary depending on the overall cable length.

13.9 Minor twisted pair variants

Loaded twisted pair A twisted pair that has intentionally added inductance, formerly common practice on telecommunication lines. The added inductors are known as load coils and reduce attenuation for voiceband frequencies but increase it on higher frequencies. Load coils prevent distortion in voiceband on very long lines.[10] In this context a line without load coils is referred to as an unloaded line.

Bonded twisted pair A twisted pair variant in which the pairs are individually bonded to increase robustness of the cable. Pioneered by Belden, it means the electrical specifications of the cable are maintained despite rough handling.

Twisted ribbon cable A variant of standard ribbon cable in which adjacent pairs of conductors are bonded and twisted together. The twisted pairs are then lightly bonded to each other in a ribbon format. Periodically along the ribbon there are short sections with no twisting to enable connectors and PCB headers to be terminated using the usual ribbon cable IDC techniques.

13.10 See also

- Balanced line
- Category 5 cable
- Ethernet over twisted pair
- Litz wire
- Registered jack
- TIA/EIA-568-B
- Tip and ring
- Copper wire and cable

13.11 References

[1] "Crosstalk dependence on number of turns/inch for twisted pair versions of the end-cap umbilical cable" (PDF).

[2] US 244426, Bell, Alexander Graham, "Telephone-circuit", issued 1881. See also TIFF format scans for USPTO 00244426

[3] *Networks: Design and Management*

[4] Anitech Systems MP 4000 Manual

[5] http://www.techfest.com/networking/cabling/ibmcs.htm

[6] Grounding for Screened and Shielded Network Cabling - Siemon

[7] "CCNA: Network Media Types".

[8] "Comparison between CAT5, CAT5e, CAT6, CAT7 Cables".

[9] "Twisted Pair Testing".

[10] cisco.com: *Understanding Line Impairments*, visited 2012-06-04

13.12 External links

- Telecommunications Virtual Museum

Chapter 14

Leaky feeder

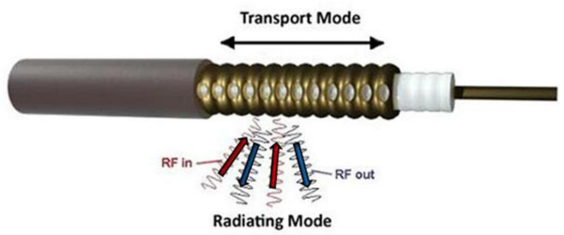


Diagram of leaky feeder cable

A **leaky feeder** is a communications system used in underground mining and other tunnel environments.[1] The layman's term "leaky feeder" implies that the cable is in some way deficient. Manufacturers and cabling professionals use the term "**radiating cable**"[2] [3] [4] as this implies that the cable is designed to radiate: something that coaxial cable is not generally supposed to do.

14.1 Principle of operation

A *leaky feeder* communication system consists of a coaxial cable run along tunnels which emits and receives radio waves, functioning as an extended antenna. The cable is "leaky" in that it has gaps or slots in its outer conductor to allow the radio signal to leak into or out of the cable along its entire length. Because of this leakage of signal, line amplifiers are required to be inserted at regular intervals, typically every 350 to 500 metres, to boost the signal back up to acceptable levels. The signal is usually picked up by portable transceivers carried by personnel. Transmissions from the transceivers are picked up by the feeder and carried to other parts of the tunnel, allowing two-way radio communication throughout the tunnel system.

The system has a limited range and because of the frequency it uses (typically VHF or UHF), transmissions cannot pass through solid rock, which limits the system to a line-of-sight application. It does, however, allow two-way mobile communication.

14.2 Applications

14.2.1 Mining

Leaky feeder has been used in the mining industry as a method of wireless communication between miners. The system is used as a primary communication system which has a transceiver small enough to be comfortably worn on a miner throughout an entire shift.[5]

14.2.2 Underground railways

Leaky feeder system is also used for underground mobile communication in mass transit railways. In Hong Kong the leaky feeder aerial was incorporated in the specification of the capital project and installed during construction.[6] This allows emergency services seamless mobile communication from the underground to the surface.

In London, London Underground uses a leaky feeder system for their internal communication network *Connect*.[7] The emergency services' communications system however was not compatible and did not work underground. The fact that this situation continued to exist after the 1987 King's Cross fire was criticized in the reports from the 7 July 2005 London bombings, where it hampered rescue efforts.[8]

An alternative to using leaky feeder in underground railways is to use Distributed Antenna System (DAS). A DAS system was deployed in some New York City Subway stations by Transit Wireless to provide WiFi and mobile phone and data coverage for customers.[9]

14.2.3 In-flight entertainment systems

Aircraft also use a leaky feeder antenna system for the latest generation of IFE systems.[10]

14.2.4 Industrial buildings

Leaky feeder is also being used in warehouses and other industrial buildings where it is difficult to get WiFi coverage using normal access points. Real life installations with 50–75 meters of leaky wire connected to the antenna input of Access Points exist, and are working fine.

14.3 See also

- Tunnel transmitter
- Through the earth mine communications

14.4 References

[1] "Improvements coming soon to mine communications". *Kentucky New Era*. Associated Press. 19 February 2007. Retrieved 6 March 2012.

[2] *Times Microwave* (PDF) [Times Microwave Radiating Cable Catalogue [http://www.timesmicrowave.com/documents/resources/Radiating%20Cable.pdf Times Microwave Radiating Cable Catalogue]]. Retrieved 11 September 2014. Missing or empty |title= (help)

[3] *Commscope* http://www.commscope.com/catalog/wireless/2147485680/product.aspx?id=68. Retrieved 13 September 2014. Missing or empty |title= (help)

[4] "Radiating cable revealed". *http://www.rfsworld.com/". Retrieved 13 September 2014.*

[5] "Basic Tutorial on Wireless Communication and Electronic Tracking: Technology Overview". Centers for Disease Control and Prevention. Retrieved 8 March 2014.

[6] "Reliability is the key for Victoria line re-signalling". Goliath.ecnext.com. 1 December 2005. Retrieved 6 March 2012.

[7] "Victoria line heads Metronet renewal". Railway Gazette. 1 August 2003. Retrieved 6 March 2012.

[8] "Communications blamed in London bomb response". PC Advisor. 23 February 2012. Retrieved 6 March 2012.

[9] Nally, Jonathan (30 September 2013). "Tunnel vision: getting New York talking". *CriticcalComms*. Retrieved 8 March 2014.

[10] *Gore and Associates* [cable-based-antennas [http://www.gore.com/en_xx/products/cables/coaxial/cable-based-antennas.html cable-based-antennas]]. Retrieved 11 September 2014. Missing or empty |title= (help)

14.5 External links

- IWT Wireless Communications and Tracking in Underground Mines - a wireless mesh alternative to leaky feeder

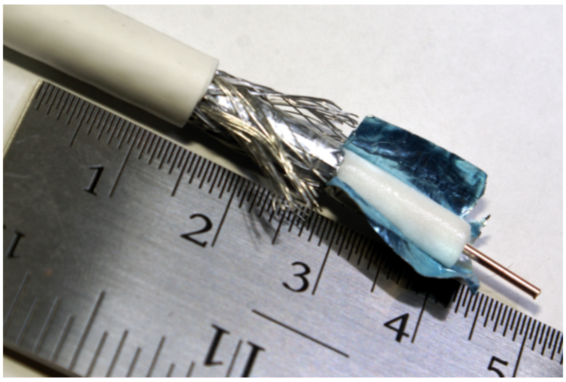
Chapter 15

RG-6

“RG6” redirects here. For the area of Reading, see RG postcode area. For the grenade launcher, see RG-6 grenade launcher.

RG-6/U is a common type of coaxial cable used in a wide variety of residential and commercial applications. The term “RG-6” itself is quite generic and refers to a wide variety of cable designs, which differ from one another in shielding characteristics, center conductor composition, dielectric type and jacket type. *RG* was originally a unit indicator (*radio guide*, or *radio grade*[1]) for bulk radio frequency (RF) cable in the U.S. military’s Joint Electronics Type Designation System. The suffix */U* means *for general utility use*. The number was assigned sequentially. The *RG* unit indicator is no longer part of the JETDS system (MIL-STD-196E) and cable sold today under the RG-6 label is unlikely to meet military specifications. In practice, the term *RG-6* is generally used to refer to coaxial cables with an 18 AWG center conductor and 75 ohm characteristic impedance.

RG-6 coaxial cable for television signals



RG-6 Coaxial cable

15.1 Applications

The most commonly recognized variety of **RG-6** is cable television (CATV) distribution coax, used to route cable television signals to and within homes, and RG-6 type cables have become the standard for CATV, mostly replacing the smaller RG-59, in recent years. CATV distribution coax typically has a copper-clad steel (CCS) center conductor and a combination aluminum foil/aluminum braid shield, typically with low coverage (about 60%). RG-6 type cables are also used in professional video applications, carrying either base band analog video signals or serial digital interface (SDI) signals; in these applications, the center conductor is ordinarily solid copper, the shielding is much heavier (typically aluminum foil/95% copper braid), and tolerances are more tightly controlled, to improve impedance stability.

15.2 Connectors

RG-6 cables typically are fitted with various types of connector at each end; in CATV distribution applications, these are typically F connector style; in professional base band video, BNC connectors; and in consumer a/v applications other than RF and CATV, RCA plugs.

15.3 Types

RG-6 is available in three different types designed for various applications. “Plain” or “house” wire is designed for indoor or external house wiring. “Flooded” cable is infused with water blocking gel for use in underground conduit or direct burial. “Messenger” or “Aerial” may contain some waterproofing but is distinguished by the addition of a steel messenger wire along its length to carry the tension involved in an aerial drop from a utility pole. "Plenum" wire comes with a special Teflon outer jacket designed for use in ventilation ducts to meet fire codes.

15.4 Attenuation/signal loss

Cables attenuate the signal proportional with the length. Attenuation increases with frequency due to the skin effect.

15.5 Specifications

RG-6 has many specifications: F6TSSV, F6TSSVcu, F6TVS, F6TVScu, F660BV, F660BVcu, F660BVF,F660BVM, F690BV, F690BVcu, F690BVF, F690BVM maximum range.

15.6 References

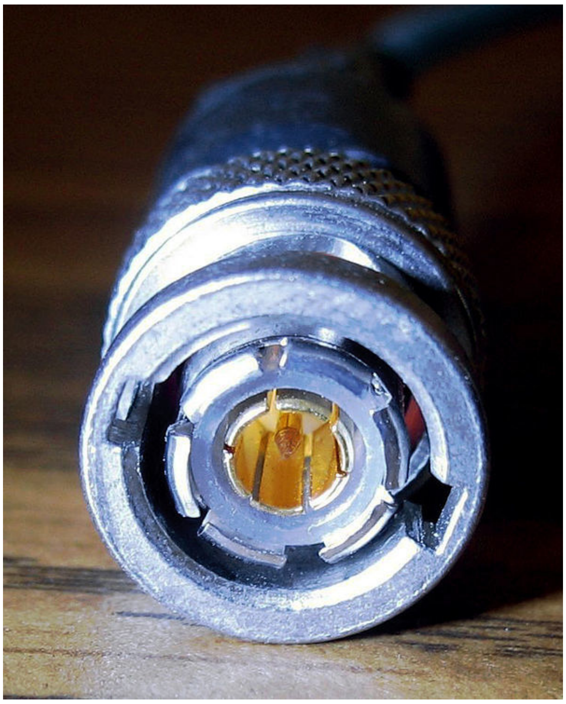
[1] 'Mike Meyers' CompTIA Network+ Certification Passport', by Glen E. Clark, edited by Christopher A. Crayton, McGraw-Hill, 3rd Edition, 2009, page 32. “Specific coax types were developed for the Ethernet standard, but a number of radio cables have very similar characteristics, and these so-called radio-grade (RG) cables also became associated with Ethernet.”

15.7 External links

- COAX History
- What Does “RG-6” Mean?

Chapter 16

Triaxial cable



Triaxial BNC connector. Newer variants have three locking lugs rather than the two used here to prevent accidental interconnection with regular BNC connectors.

Triaxial cable, often referred to as **triax** for short, is a type of electrical cable similar to coaxial cable, but with the addition of an extra layer of insulation and a second conducting sheath. It provides greater bandwidth and rejection of interference than coax, but is more expensive.[1][2]

16.1 Applications

16.1.1 Television Production

The most common use of triaxial cable is in television industry as a connecting cable between a camera and its CCU. The outer sheath is commonly used as a protective earth conductor. The core provides both power and signal connections, with the return for the power being provided through the inner screen. Through frequency-division multiplexing, the camera can send audio and video signals along the triax while the CCU can send camera control information, such as exposure settings, intercom, return audio and video (usually that of the program), and tally (a signal alerting the operator that their camera is on the air)and power for the camera.[1]

Venues that host television productions fairly often, such as sports arenas, will usually have triaxial cables run from the location of the TV truck to common camera locations throughout the building. This is convenient for visiting television crews, who can simply plug into existing cable runs instead of having to run their own cables and remove them after filming.

- In 1992 N.V. Philips, Breda received the Outstanding Achievement in Technical/Engineering Development Award from the National Academy of Television Arts & Sciences for Triaxial cable Technology for Color Television Cameras. Also see Norelco and BTS[3]

16.1.2 Decline of Triax in Television

With the increasing bandwidth requirements of developments such as 4K/UHDTV, HFR (high frame rate) and HDR (high dynamic range) the use of triax is declining in the TV industry. Most of the recently developed broadcast cameras from the leading manufacturers have hybrid single-mode fibre and copper power cores which supersede the older triax connectivity. The advantages of the hybrid copper/fibre over triax cable are noise immunity due to the optical isolation and extremely high bandwidth.

16.1.3 Current measurements

Another application for triaxial cables is in taking precision low-current measurements where the leakage current through the insulator between the core and shield would normally alter the measurements. The core (known as the **force**) and the inner shield (known as the **guard**) are kept at approximately the same electrical potential by a voltage buffer/follower, thus the leakage current between them is zero for all practical purposes, despite the imperfections of the insulation. Instead, the leakage current occurs between the inner and outer shields, which does not matter since that current will be supplied by the buffer circuit rather than the device under test and will not affect measurements. This technique can provide almost perfect elimination of leakage current but becomes less effective at higher frequencies as the buffer cannot follow the measured voltage.

See also: Driven shield

16.2 See also

- Twinaxial cabling
- Coaxial cable

16.3 References

[1] "Video triaxial cables". *ePanorama.net*.

[2] "ATIS Telecom Glossary - triaxial cable". Alliance for Telecommunications Industry Solutions.

[3] emmyonline 1992 N.V. Philips, Breda received the Outstanding Achievement in Technical/Engineering Development Award from the National Academy of Television Arts & Sciences for Triaxial cable

Chapter 17

Balanced line

"Balanced" redirects here. For other uses, see Balance (disambiguation).

In telecommunications and professional audio, a **balanced line** or **balanced signal pair** is a transmission line consisting of two conductors of the same type, each of which have equal impedances along their lengths and equal impedances to ground and to other circuits.[1] The chief advantage of the balanced line format is good rejection of external noise when fed to a differential amplifier. Common forms of balanced line are twin-lead, used for radio frequency signals and twisted pair, used for lower frequencies. They are to be contrasted to unbalanced lines, such as coaxial cable, which is designed to have its return conductor connected to ground, or circuits whose return conductor actually is ground. Balanced and unbalanced circuits can be interconnected using a transformer called a balun.

Circuits driving balanced lines must themselves be balanced to maintain the benefits of balance. This may be achieved by transformer coupling or by merely balancing the impedance in each conductor.

Lines carrying symmetric signals (those with equal but opposite voltages to ground on each leg) are often incorrectly referred to as "balanced", but this is actually differential signaling. Balanced lines and differential signaling are often used together, but they are not the same thing. Differential signalling does not make a line balanced, nor does noise rejection in balanced cables require differential signalling.

17.1 Explanation

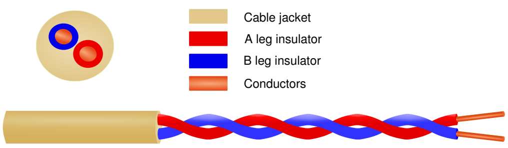


Fig. 1. Balanced line in twisted pair format. This line is intended for use with 2-wire circuits.

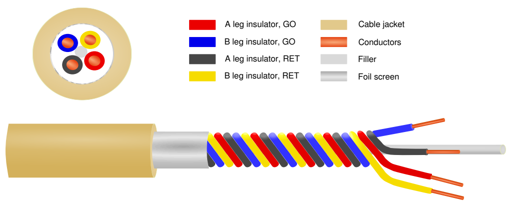


Fig. 2. Balanced line in star quad format. This line is intended for use with 4-wire circuits or two 2-wire circuits. It is also used with microphone signals in professional audio.

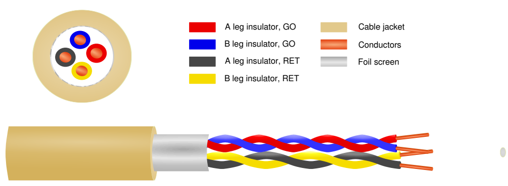


Fig. 3. Balanced line in DM quad format. This line is intended for use with 4-wire circuits or two 2-wire circuits.

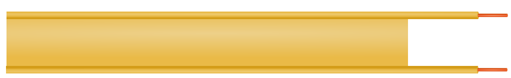


Fig. 4. Balanced line in twin lead format. This line is intended for use with RF circuits, particularly antennae.

Transmission of a signal over a balanced line reduces the influence of noise or interference due to external stray electric fields. Any external signal sources tend to induce only a common mode signal on the line, and the balanced impedances to ground minimizes differential pickup due to stray electric fields. The conductors are sometimes twisted together to ensure that each conductor is equally exposed to any external magnetic fields that could induce unwanted noise.

Some balanced lines also have electromagnetic shielding to reduce the amount of noise introduced.

A balanced line allows a differential receiver to reduce the noise on a connection by rejecting common-mode interference. The lines have the same impedance to ground, so the interfering fields or currents induce the same voltage in both wires. Since the receiver responds only to the difference between the wires, it is not influenced by the induced noise voltage. If twisted pair becomes unbalanced, for example due to insulation failure, noise will be induced. Examples of twisted pairs include Category 5 cable.

Compared to unbalanced circuits, balanced lines reduce the amount of noise per distance, allowing a longer cable run to be practical. This is because electromagnetic interference will affect both signals the same way. Similarities between the two signals are automatically removed at the end of the transmission path when one signal is subtracted from the other.

17.2 Telephone systems

The first application for balanced lines was for telephone lines. Interference that was of little consequence on a telegraph system (which is in essence digital) could be very disturbing for a telephone user. The initial format was to take two single-wire unbalanced telegraph lines and use them as a pair. This proved insufficient, however, with the growth of electric power transmission which tended to use the same routes. A telephone line running alongside a power line for many miles will inevitably have more interference induced in one leg than the other since one of them will be nearer to the power line. This issue was addressed by swapping the positions of the two legs every few hundred yards with a cross-over, thus ensuring that both legs had equal interference induced and allowing common-mode rejection to do its work. As the telephone system grew, it became preferable to use cable rather than open wires to save space, and also to avoid poor performance during bad weather. The cable construction used for balanced telephone cables was twisted pair, however, this did not become widespread until repeater amplifiers became available. For an unamplified telephone line, a twisted pair cable could only manage a maximum distance of 30 km. Open wires, on the other hand, with their lower capacitance had been used for enormous distances - the longest was the 1500 km from New York to Chicago built in 1893. Loading coils were used to improve the distance achievable with cable but the problem was not finally overcome until amplifiers started to be installed in 1912.[2] Twisted pair balanced lines are still widely used for the telephone subscribers local end.[3]

Telephone trunk lines, and especially frequency division multiplexing carrier systems, are usually 4-wire circuits rather than 2-wire circuits (or at least they were before fibre-optic became widespread) and require a different kind of cable. This format requires the conductors to be arranged in two pairs, one pair for the sending (go) signal and the other for the return signal. The greatest source of interference on this kind of transmission is usually the crosstalk between the go and return circuits themselves. The most common cable format is star quad, where the diagonally opposite conductors form the pairs. This geometry gives maximum common mode rejection between the two pairs. An alternative format is DM[4] quad which consists of two twisted pairs with the twisting at different pitches.[5]

17.3 Audio systems

Main article: Balanced audio

An example of balanced lines is the connection of

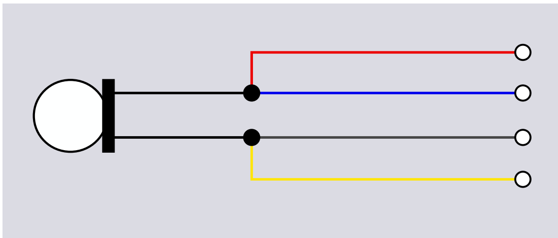


Fig. 5. Microphones connected to star quad cable join together diametrically opposite conductors to maintain balance. This is different from the usage on 4-wire circuits. The colours in this diagram correspond with the colouring in figure 2.

microphones to a mixer in professional systems. Classically, both dynamic and condenser microphones used transformers to provide a differential-mode signal. While transformers are still used in the large majority of modern dynamic microphones, more recent condenser microphones are more likely to use electronic drive circuitry. Each leg, irrespective of any signal, should have an identical impedance to ground. Pair cable (or a pair-derivative such as star quad) is used to maintain the balanced impedances and close twisting of the cores ensures that any interference is common to both conductors. Providing that the receiving end (usually a mixing console) does not disturb the line balance, and is able to ignore common-mode (noise) signals, and can extract differential ones, then the system will have excellent immunity to induced interference.

Typical professional audio sources, such as microphones, have three-pin XLR connectors. One is the shield or chassis ground, while the other two are signal connections. These signal wires carry two copies of the same signal, but with opposite polarity. (They are often termed “hot” and “cold,” and the AES14-1992(r2004) Standard [and EIA Standard RS-297-A] suggest that the pin that carries the positive signal that results from a positive air pressure on a transducer will be deemed 'hot'. Pin 2 has been designated as the 'hot' pin, and that designation serves useful for keeping a consistent polarity in the rest of the system.) Since these conductors travel the same path from source to destination, the assumption is that any interference is induced upon both conductors equally. The appliance receiving the signals compares the difference between the two signals (often with disregard to electrical ground) allowing the appliance to ignore any induced electrical noise. Any induced noise would be present in equal amounts and in identical polarity on each of the balanced signal conductors, so the two signals' difference from each other would be unchanged. The successful rejection of induced noise from the desired signal depends in part on the balanced signal conductors receiving the same amount and type of interference. This typically leads to twisted, braided, or co-jacketed cables for use in balanced signal transmission.

17.4 Balanced and differential

Main article: Balanced circuit

Most explanations of balanced lines assume symmetric (antiphase) signals but this is an unfortunate confusion - signal symmetry and balanced lines are quite independent of each other. Essential in a balanced line is matched impedances in the driver, line and receiver. These conditions ensure that external noise affects each leg of the differential line equally and thus appears as a common mode signal that is removed by the receiver. There are balanced drive circuits that have excellent common-mode impedance matching between "legs" but do *not* provide symmetric signals.[6][7] Symmetric differential signals exist to prevent interference *to* other circuits - the electromagnetic fields are canceled out by the equal and opposite currents. But they are not necessary for interference rejection *from* other circuits.

17.5 Baluns

Main article: Balun

To convert a signal from balanced to unbalanced requires a balun. For example, baluns can be used to send line level audio or E-carrier level 1 signals over coaxial cable (which is unbalanced) through 300 feet (91 m) of Category 5 cable by using a pair of baluns at each end of the CAT5 run. The balun takes the unbalanced signal, and creates an inverted copy of that signal. It then sends these 2 signals across the CAT5 cable as a balanced signal. Upon reception at the other end, the balun takes the difference of the two signals, thus removing any noise picked up along the way and recreating the unbalanced signal.

A once common application of a radio frequency balun was found at the antenna terminals of a television receiver. Typically a 300-ohm balanced twin lead antenna input could only be connected to a coaxial cable from a cable TV system through a balun.

17.6 Characteristic impedance

The characteristic impedance Z_0 of a transmission line is an important parameter at higher frequencies of operation. For a parallel 2-wire transmission line,

$$Z_0 = \frac{1}{\pi}\sqrt{\frac{\mu}{\epsilon}} \ln\left(\frac{l}{R} + \sqrt{\left(\frac{l}{R}\right)^2 - 1}\right),$$

where l is half the distance between the wire centres, R is the wire radius and μ , ϵ are respectively the permeability and permittivity of the surrounding medium. A commonly used approximation that is valid when the wire separation is much larger than the wire radius and in the absence of magnetic materials is

$$Z_0 = \frac{120}{\sqrt{\epsilon_r}} \ln\left(\frac{2l}{R}\right),$$

where ϵ_r is the relative permittivity of the surrounding medium.

17.7 Electric power lines

In electric power transmission, the three conductors used for three-phase power transmission are referred to as a balanced line since the instantaneous sum of the three line voltages is nominally zero. However, *balance* in this field is referring to the symmetry of the source and load: it has nothing to do with the impedance balance of the line itself, the sense of the meaning in telecommunications.

For the transmission of single-phase electric power as used for railway electrification systems, two conductors are used to carry in-phase and out-of-phase voltages such that the line is balanced.

Bipolar HVDC lines at which each pole is operated with the same voltage toward ground are also balanced lines.

17.8 See also

- Differential pair

17.8.1 Balanced transmission standards

- RS-422

- RS-485
- Low-voltage differential signalling (LVDS)

17.9 References

[1] Young EC, *The Penguin Dictionary of Electronics*, 1988, ISBN 0-14-051187-3

[2] Huurdeman, p.323.

[3] Huurdeman, p.314-316.

[4] Dieselhorst-Martin, the inventors.GB 190312526, "Improved Manufacture of Electric Cables"

[5] Huurdeman, p.320.

[6] Graham Blyth. "Audio Balancing Issues". Retrieved 2014-10-27. Let's be clear from the start here: if the source impedance of each of these signals was not identical i.e. balanced, the method would fail completely, the matching of the differential audio signals being irrelevant, though desirable for headroom considerations.

[7] "Part 3: Amplifiers". *Sound system equipment* (Third edition ed.). Geneva: International Electrotechnical Commission. 2000. p. 111. IEC 602689-3:2001. Only the common-mode impedance balance of the driver, line, and receiver play a role in noise or interference rejection. This noise or interference rejection property is independent of the presence of a desired differential signal.

- Huurdeman, A. A., *The worldwide history of telecommunications*, Wiley-IEEE, 2003.

17.10 External links

- Balanced Lines, Phantom Powering, Grounding, and Other Arcane Mysteries — from Mackie;

Chapter 18

Cable Entry System

Cable entry systems are used for routing cables, corrugated conduits or pneumatic hoses into switch cabinets, electrical enclosures and machines or in large heavy-duty vehicles, rolling stock and ships. Possible requirements can be high ingress protection rates[1] or integrated strain relief.[2]

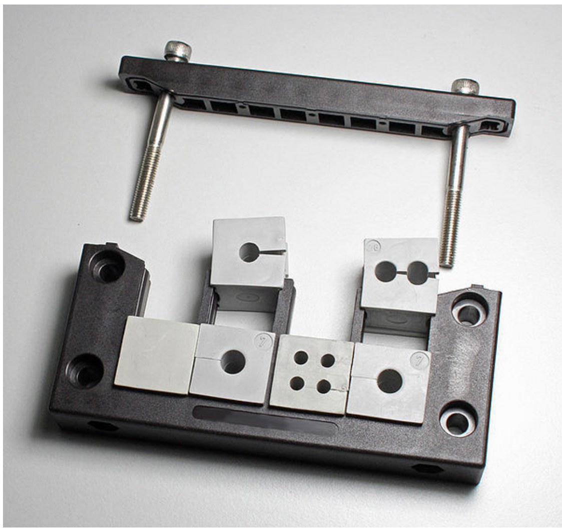
It is being differentiated between entry systems for routeing standard cables (without connectors) with a high packing density and split cable entry systems which enable routeing of pre-terminated cables (with connectors) or complete cable harnesses.

18.1 Cable entry systems for cables without connectors

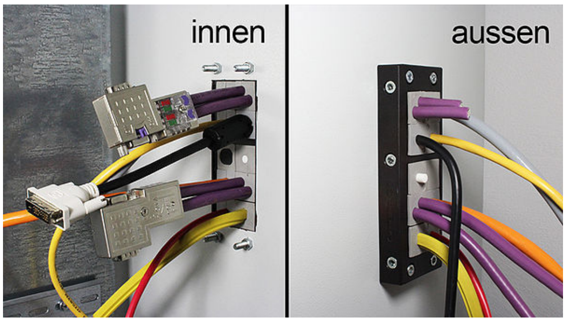
Cable entry plate for standard cables without connectors

For routing of standard cables and other electrical lines through machine or enclosure walls, cable glands, self-sealing grommets or cable entry plates can be used to seal the cut-outs required for passing the cables through. This protects the inside of an enclosure or machine from dirt, dust or liquids. Cable glands and self-sealing grommets are usually designed for entering single or just a few cables. By utilising a cable entry plate, many cables with different diameters can be routed. Depending on the type, very high packing densities or ingress protection classes up to IP 67/68 (according to IEC 60529) can be achieved.

18.2 Split cable entry systems for cables with connectors



Split cable entry for multiple pre-terminated cables



Mounted cable entry on a switch cabinet wall

For routeing cables which are already assembled with connectors, split cable entry systems have been developed. The divisibility of these systems provides two advantages. The warranty on pre-terminated cables remains since the connectors don't have to be cut and soldered again after entering the cables. The other advantage is that assembly can be done subsequently because the split cable entries are usually built around the existing lines. Most split cable entries consist of a split hard frame, made of plastic or sometimes aluminium (e.g. utilised in food industry) and one or several split sealing inserts, usually made of elastomer. The insert matching the cable diameter is placed around the cable and fixed inside the cable entry frame. Thus allowing strain relief for the cables according to EN 50262 as well as ingress protection classes up to IP 65/66/67.

18.3 Frame sizes and standards

Cable entries are offered in different sizes, but most of them are based on cut-out dimensions and drilling templates for standard industrial connectors (10-pole, 16-pole, 24-pole). Round cable entry plates are usually produced in metric standard sizes (M25 – M63)

Since cable entry systems are utilised in many different applications, it is very important to comply with standards like e.g. IP rating (according to EN 60529), UL listing, GL listing (for marine applications), national or European railway standards or ATEX certifications the enable use in potentially explosive atmospheres.

18.4 History

From the 50s on, machines and switch cabinets were more and more wired by using heavy-duty industrial connectors but the increasing cost pressure forced engineers to look for more cost-effective solutions and to decrease the risk of miswiring. In the 90s cable entry systems have been developed as an alternative to heavy-duty industrial connectors and cable glands.

18.5 References

[1] Understanding the IP (Ingress Protection) Ratings

[2] BS EN 50262:1999 Cable glands for electrical installations

Chapter 19

Cable tray

In the electrical wiring of buildings, a **cable tray** system is used to support insulated electric cables used for power distribution and communication. Cable trays are used as an alternative to open wiring or electrical conduit systems, and are commonly used for cable management in commercial and industrial construction. They are especially useful in situations where changes to a wiring system are anticipated, since new cables can be installed by laying them in the tray, instead of pulling them through a pipe.

19.1 Types

Several types of tray are used in different applications. A solid-bottom tray provides the maximum protection to cables, but requires cutting the tray or using fittings to enter or exit cables. A deep, solid enclosure for cables is called a cable channel or cable trough.[1]

A ventilated tray has openings in the bottom of the tray, allowing some air circulation around the cables, water drainage, and allowing some dust to fall through the tray. Small cables may exit the tray through the ventilation openings, which may be either slots or holes punched in the bottom. A ladder tray has the cables supported by a traverse bar, similarly to the rungs of a ladder, at regular intervals on the order of 4 to 12 inches (100 to 300 mm).

Ladder and ventilated trays may have solid covers to protect cables from falling objects, dust, and water. Tray covers for use outdoors or in dusty locations may have a peaked shape to shed debris including dust, ice or snow. Lighter cable trays are more appropriate in situations where a great number of small cables are used, such as for telephone or computer network cables. These trays may be made of wire mesh, called “cable basket”,[1] or be designed in the form of a single central spine (rail) with ribs to support the cable on either side.

Large power cables laid in the tray may require support blocks to maintain spacing between conductors, to prevent overheating of the wires. Smaller cables may be laid unsecured in horizontal trays, or secured with cable ties to the bottom of vertically mounted trays.

To maintain support of cables at changes of elevation or direction of a tray, a large number of specialized cable tray fittings are made compatible with each style and manufacturer. Horizontal elbows change direction of a tray in the same plane as the bottom of the tray and are made in 30, 45 and 90 degree forms; inside and outside elbows are for changes perpendicular to the tray bottom. These can be in various shapes including tees and crosses. Some manufacturers and types provide adjustable elbows, useful for field-fitting a tray around obstacles or around irregular shapes.[2]

Various clamping, supporting and splicing accessories are used with the cable tray to provide a complete functional tray system. For example, different sizes of cable tray used within one run can be connected with reducers.

19.2 Materials used

Common cable trays are made of galvanized steel, stainless steel, aluminum, or glass-fiber reinforced plastic. The material for a given application is chosen based on where it will be used. Galvanized tray may be made of pre-galvanized steel sheet fabricated into tray, or may be hot-dip galvanized after fabrication. When galvanized tray is cut to length in the field, usually the cut surface will be painted with a zinc-rich compound to protect the metal from corrosion.

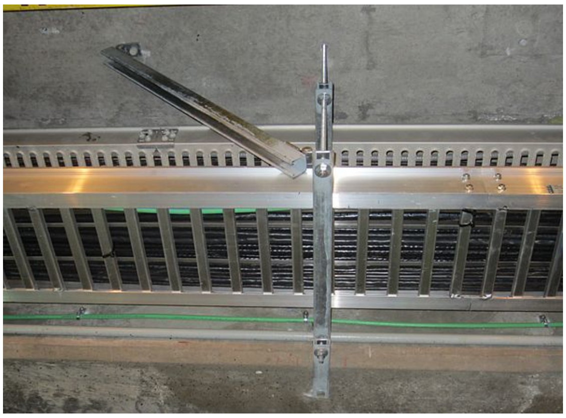
19.3 Fire safety concerns and solutions

Combustible cable jackets may catch on fire and cable fires can thus spread along a cable tray within a structure. This is easily prevented through the use of fire-retardant cable jackets, or fireproofing coatings applied to installed cables. Heavy coatings or long fire-stops may require adjustment of the cable current ratings, since such fireproofing measures may reduce the heat dissipation of installed cables.[3]

Regular housecleaning is important for safety, as cable trays are often installed in hard to reach places. Combustible dust and clutter may accumulate if the trays are not routinely checked and kept clean.

Plastic and fibreglass reinforced plastic cable trays are combustible; the effect is mitigated through the use of fire retardants or fireproofing.

Ferrous cable trays expand with the increasing heat from accidental fire. This has been proven by the German Otto-Graf-Institut Test Report III.1-80999/Tei/tei "Supplementary Test On The Topic Of Mechanical Force Acting On Cable Penetration Firestop Systems During The Fire Test", dated 23 October 1984, to dislodge "soft" firestops, such as those made of fibrous insulations with rubber coatings. This also applies to any silicone foam seals, but is easily remedied through the use of firestop mortars of sufficient compression strength and thickness, as shown above. Also, some building codes mandate that penetrants such as cable trays are installed in such ways so as to avoid their contribution to the collapse of a firewall.



Seismic bracing of a cable tray trapeze support. The diagonal strut and horizontal tie restrains motion longitudinally and laterally.

19.4 See also

- Cable
- Passive fire protection
- Circuit integrity
- Firestop
- Fire test
- Fireproofing
- Intumescent
- Endothermic
- Conduit (electrical)

19.5 References

[1] W.E. Steward and R.A. Beck, *Modern Wiring Practice*, Newnes, London, 2010 ISBN–13: 978-1-85617-692-7, pages 266-272.

[2] http://www.tnb.com/contractor/docs/cabletray_us_revised_lr.pdf One manufacturer's cable tray catalog, retrieved 2010 Aug 11.

[3] Jones, Dean. "Cable Trays Make it Easy to Repair & Maintain Cables in Industrial Settings". Commercial Electricians Perth. Retrieved 15 September 2014.

19.6 External links

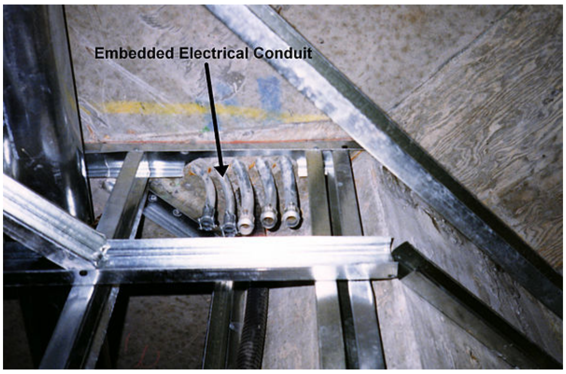
- Best Practice Guide

Chapter 20

Electrical conduit

This illustration shows electrical conduit risers, looking up inside a fire-resistance rated shaft, as seen entering bottom of a firestop. The firestop is made of firestop mortar on top and mineral wool on the bottom. Raceways are used to protect cables from damage.

Electrical conduit and bus duct in a building at Texaco Nanticoke refinery in Nanticoke, Ontario, 1980s.



Conduit embedded in concrete structure for distribution of cables throughout this highrise apartment building in Mississauga, Ontario, Canada

An **electrical conduit** is a tube used to protect and route electrical wiring in a building or nonbuilding structure. Electrical conduit may be made of metal, plastic, fiber, or fired clay. Most conduit is rigid, but flexible conduit is used for some purposes.

Conduit is generally installed by electricians at the site of installation of electrical equipment. Its use, form, and installation details are often specified by wiring regulations, such as the US National Electrical Code (NEC) and other building codes.

20.1 History

Some early electric lighting installations made use of existing gas pipe serving gas light fixtures which had been converted to electric lamps. Since this technique provided very good mechanical protection for interior wiring, it was extended to all types of interior wiring and by the early 20th century purpose-built couplings and fittings were manufactured for electrical use.

However, most electrical codes now prohibit the routing of electrical conductors through gas piping, due to concerns about damage to electrical insulation from the rough interiors of pipes and fittings commonly used for gas.

20.2 Comparison with other wiring methods

Electrical conduit provides very good protection to enclosed conductors from impact, moisture, and chemical vapors. Varying numbers, sizes, and types of conductors can be pulled into a conduit, which simplifies design and construction compared to multiple runs of cables or the expense of customized composite cable. Wiring systems in buildings may be subject to frequent alterations. Frequent wiring changes are made simpler and safer through the use of electrical conduit, as existing conductors can be withdrawn and new conductors installed, with little disruption along the path of the conduit.

A conduit system can be made waterproof or submersible. Metal conduit can be used to shield sensitive circuits from electromagnetic interference, and also can prevent emission of such interference from enclosed power cables.

When installed with proper sealing fittings, a conduit will not permit the flow of flammable gases and vapors, which provides protection from fire and explosion hazard in areas handling volatile substances.

Some types of conduit are approved for direct encasement in concrete. This is commonly used in commercial buildings to allow electrical and communication outlets to be installed in the middle of large open areas. For example, retail display cases and open-office areas use floor-mounted conduit boxes to connect power and communications cables.

Both metal and plastic conduit can be bent at the job site to allow a neat installation without excessive numbers of manufactured fittings. This is particularly advantageous when following irregular or curved building profiles. Special equipment is used to bend the conduit without kinking or denting it.

The cost of conduit installation is higher than other wiring methods due to the cost of materials and labor. In applications such as residential construction, the high degree of physical damage protection may not be not required, so the expense of conduit is not warranted. Conductors installed within conduit cannot dissipate heat as readily as those installed in open wiring, so the current capacity of each conductor must be reduced (derated) if many are installed in one conduit. It is impractical, and prohibited by wiring regulations, to have more than 360 degrees of total bends in a run of conduit, so special outlet fittings must be provided to allow conductors to be installed without damage in such runs.

Some types of metal conduit may also serve as a useful bonding conductor for grounding (earthing), but wiring regulations may also dictate workmanship standards or supplemental means of grounding for certain types. While metal conduit may sometimes be used as a grounding conductor, the circuit length is limited. For example, a long run of conduit as grounding conductor may have too high an electrical resistance, and not allow proper operation of overcurrent devices on a fault.

20.3 Types

Conduit systems are classified by the wall thickness, mechanical stiffness, and material used to make the tubing. Materials may be chosen for mechanical protection, corrosion resistance, and overall cost of the installation (labor plus material cost). Wiring regulations for electrical equipment in hazardous areas may require particular types of conduit to be used to provide an approved installation.

20.3.1 Metal

Rigid metal conduit (RMC) is a thick-walled threaded tubing, usually made of coated steel, stainless steel or aluminum.

Galvanized rigid conduit (GRC) is galvanized steel tubing, with a tubing wall that is thick enough to allow it to be threaded. Its common applications are in commercial and industrial construction.[1]

Intermediate metal conduit (IMC) is a steel tubing heavier than EMT but lighter than RMC. It may be threaded.

Electrical metallic tubing (EMT), sometimes called thin-wall, is commonly used instead of galvanized rigid conduit (GRC), as it is less costly and lighter than GRC. EMT itself is not threaded, but can be used with threaded fittings that clamp to it. Lengths of conduit are connected to each other and to equipment with clamp-type fittings. Like GRC, EMT is more common in commercial and industrial buildings than in residential applications. EMT is generally made of coated steel, though it may be aluminum.

Aluminum conduit, similar to galvanized steel conduit, is a rigid tube, generally used in commercial and industrial applications where a higher resistance to corrosion is needed. Such locations would include food processing plants, where large amounts of water and cleaning chemicals would make galvanized conduit unsuitable. Aluminum cannot be directly embedded in concrete, since the metal reacts with the alkalis in cement. The conduit may be coated to prevent corrosion by incidental contact with concrete. Aluminum conduit is generally lower cost than steel in addition to having a lower labor cost to install, since a length of aluminum conduit will have about one-third the weight of an equally-sized rigid steel conduit.[2]

20.3.2 Non-metal

PVC conduit is the lightest in weight compared to other conduit materials, and usually lower in cost than other forms of conduit. In North American electrical practice, it is available in three different wall thicknesses, with the thin-wall variety only suitable for embedded use in concrete, and heavier grades suitable for direct burial and exposed work. Most of the various fittings made for metal conduit are also available in PVC form. The plastic material resists moisture and many corrosive substances, but since the tubing is non-conductive an extra bonding (grounding) conductor must be pulled into each conduit. PVC conduit may be heated and bent in the field, by using special heating tools designed for the purpose.

Plastic tubing for use as electrical conduit.

Joints to fittings are made with slip-on solvent-welded connections, which set up rapidly after assembly and attain full strength in about one day. Since slip-fit sections do not need to be rotated during assembly, the special union fittings used with threaded conduit (such as Ericson) are not required. Since PVC conduit has a higher coefficient of thermal expansion than other types, it must be mounted to allow for expansion and contraction of each run. Care should be taken when installing PVC underground in multiple or parallel run configurations due to mutual heating effect of densely packed cables, because the conduit will deform when heated.

Rigid nonmetallic conduit (RNC) is a non-metallic unthreaded smooth-walled tubing.

Electrical nonmetallic tubing (ENT) is a thin-walled corrugated tubing that is moisture-resistant and flame retardant. It is pliable such that it can be bent by hand, and is often flexible although the fittings are not. It is not threaded due to its corrugated shape, although some fittings might be.

20.3.3 Flexible

Flexible metallic conduit used in an underground parking facility.

Flexible conduits are used to connect to motors or other devices where isolation from vibration is useful, or where an excess number of fittings would be needed to use rigid connections. Electrical codes may restrict the length of a run of some types of flexible conduit.

Flexible metallic conduit (FMC, informally called *greenfield* or *flex*) is made by the helical coiling of a self-interlocked ribbed strip of aluminum or steel, forming a hollow tube through which wires can be pulled. FMC is used primarily in dry areas where it would be impractical to install EMT or other non-flexible conduit, yet where metallic strength to protect conductors is still required. The flexible tubing does not maintain any permanent bend, and can flex freely.

FMC may be used as an equipment grounding conductor if specific provisions are met regarding the trade size and length of FMC used, depending on the amperage of the circuits contained in the conduit. In general, an equipment grounding conductor must be pulled through the FMC with an ampacity suitable to carry the fault current likely imposed on the largest circuit contained within the FMC.

Liquidtight flexible metal conduit (LFMC) is a metallic flexible conduit covered by a waterproof plastic coating. The interior is similar to FMC.

Flexible metallic tubing (FMT) is not the same as flexible metallic conduit (FMC) which is described in National Electrical Code (NEC) Article 348. FMT is a raceway, but not a conduit and is described in a separate NEC Article 360. It only comes in 1/2" & 3/4" trade sizes, whereas FMC is sized 1/2" ~ 4" trade sizes. NEC 360.2 describes it as: "A raceway that is circular in cross section, flexible, metallic and liquidtight without a nonmetallic jacket."

Liquidtight flexible nonmetallic conduit (LFNC) refers to several types of flame-resistant non-metallic tubing. Interior surfaces may be smooth or corrugated. There may be integral reinforcement within the conduit wall. It is also known as FNMC.

20.3.4 Underground

Conduit may be installed underground between buildings, structures, or devices to allow installation of power and communication cables. An assembly of these conduits, often called a duct bank, may either be directly buried in earth, or encased in concrete (sometimes with reinforcing rebar to aid against shear forces). Alternatively, a duct bank may be installed in a utility tunnel. A duct bank will allow replacement of damaged cables between buildings or additional power and communications circuits to be added, without the expense of re-excavation of a trench. While metal conduit is occasionally used for burial, usually PVC, polyethylene or polystyrene plastics are now used due to lower cost, easier installation, and better resistance to corrosion.

Formerly, compressed asbestos fiber mixed with cement (such as transite) was used for some underground installations. Telephone and communications circuits were typically installed in fired-clay conduit.

20.3.5 Cost comparison

Exact ratios of installation labor, weight and material cost vary depending on the size of conduit, but the values for 3/4 inch (21 metric) trade size are representative.[3]

20.4 Fittings

Despite the similarity to pipes used in plumbing, purpose-designed electrical fittings are used to connect conduit.

Box connectors join conduit to a junction box or other electrical box. A typical box connector is inserted into a knockout in a junction box, with the threaded end then being secured with a ring (called a **lock nut**) from within the box, as a bolt would be secured by a nut. The other end of the fitting usually has a screw or compression ring which is tightened down onto the inserted conduit. Fittings for non-threaded conduits are either secured with set screws or with a compression nut that encircles the conduit. Fittings for general purpose use with metal conduits may be made of die-cast zinc, but where stronger fittings are needed, they are made of copper-free aluminum or cast iron.

Couplings connect two pieces of conduit together.

Sometimes the fittings are considered sufficiently conductive to *bond* (electrically unite) the metal conduit to a metal junction box (thus sharing the box's ground connection); other times, **grounding bushings** are used which have bonding jumpers from the bushing to a grounding screw on the box.[4]

Unlike water piping, if it the conduit is to be watertight, the idea is to keep water *out*, not in. In this case, gaskets are used with special fittings, such as the weatherhead leading from the overhead electrical mains to the electric meter.

Flexible metal conduit usually uses fittings with a clamp on the outside of the box, just like bare cables would.

20.4.1 Conduit bodies

A **conduit body** can be used to provide pulling access in a run of conduit, to allow more bends to be made in a particular section of conduit, to conserve space where a full size bend radius would be impractical or impossible, or to split a conduit path into multiple directions. Conductors may *not* be spliced inside a conduit body, unless it is specifically listed for such use.

Conduit bodies differ from junction boxes in that they are not required to be individually supported, this makes them very useful in practical applications. Conduit bodies are commonly referred to as **condulets**, a term trademarked by Cooper Crouse-Hinds company, a division of Cooper Industries.

Conduit bodies come in various types, moisture ratings, and materials, including galvanized steel, aluminum, and PVC. Depending on the material, they use different mechanical methods for securing conduit. Among the types are:

- L-shaped bodies ("Ells") include the LB, LL, and LR, where the inlet is in line with the access cover and the outlet is on the back, left and right, respectively. In addition to providing access to wires for pulling, "L" fittings allow a 90 degree turn in conduit where there is insufficient space for a full-radius 90 degree sweep (curved conduit section).

- T-shaped bodies ("Tees") feature an inlet in line with the access cover and outlets to both the cover's left and right.

- C-shaped bodies ("Cees") have identical openings above and below the access cover, and are used to pull conductors in a straight runs as they make no turn between inlet and outlet.

- "Service Ell" bodies (SLBs), shorter ells with inlets flush with the access cover, are frequently used where a circuit passes through an exterior wall from outside to inside.

20.5 Other wireways

20.5.1 Surface mounted raceway (wire molding)

This type of "decorative" conduit is designed to provide an aesthetically acceptable passageway for wiring without hiding it inside or behind a wall. This is used where additional wiring is required, but where going through a wall would be difficult or require remodeling. The conduit has an open face with removable cover, secured to the surface, and wire is placed inside. Plastic raceway is often used for telecommunication wiring, such as network cables in an older structure, where it is not practical to drill through concrete block.

Advantages

- Allows adding new wiring to an existing building without removing or cutting holes into the drywall, lath and plaster, concrete, or other wall finish.

- Allows circuits to be easily locatable and accessible for future changes, thus enabling minimum effort upgrades.

Disadvantages

- Appearance may not be acceptable to all observers.

20.5.2 Trunking

The term *trunking* is used in the United Kingdom for electrical wireways, generally rectangular in cross section with removable lids.

Mini trunking is a term used in the UK for small form-factor (usually 6 mm to 25 mm square or rectangle sectioned) PVC wireways.[5]

In North American practice, *wire trough* and *lay-in wireways* are terms used to designate similar products. Wall duct raceway[6][7][8][9] is the name give to the type that can be enclosed in a wall.

20.5.3 Innerducts

Innerducts are subducts that can be installed in existing underground conduit systems to provide clean, continuous, low-friction paths for placing optical cables, which have relatively low pulling tension limits. They provide a means for subdividing conventional conduit that was originally designed for single, large-diameter metallic conductor cables into multiple channels for smaller optical cables.

Innerducts are typically small-diameter, semi-flexible subducts. According to Telcordia GR-356, there are three basic types of innerduct: smoothwall, corrugated, and ribbed.[10] These various designs are based on the profile of the inside and outside diameters of the innerduct. The need for a specific characteristic or combination of characteristics, such as pulling strength, flexibility, or the lowest coefficient of friction, dictates the type of innerduct required.

Beyond the basic profiles or contours (smoothwall, corrugated, or ribbed), innerduct is also available in an increasing variety of multiduct designs. Multiduct may be either a composite unit consisting of up to four or six individual innerducts that are held together by some mechanical means, or a single extruded product having multiple channels through which to pull several cables. In either case, the multiduct is coilable, and can be pulled into existing conduit in a manner similar to that of conventional innerduct.

20.6 Passive fire protection

Conduit is of relevance to both firestopping, where they become penetrants, and fireproofing, where circuit integrity measures can be applied on the outside to keep the internal cables operational during an accidental fire. The British standard BS476 also considers internal fires, whereby the fireproofing must protect the surroundings from cable fires. Any external treatments must consider the effect upon ampacity derating due to internal heat buildup.

20.7 See also

- Cable
- Cable tray
- Circuit integrity
- Electrical wiring
- Firestop
- Junction box
- Passive fire protection
- Pipe
- Pipe thread
- Panzergewinde (steel conduit thread)
- Utility tunnel

20.8 Notes

[1] R.K. Clidero *Applications of Electrical Construction*, General Publishing Co., Don Mills Ontario Canada, 1975, ISBN 0-7736-5011-3

[2] R. S. Means *Electrical Cost Data 22nd Edition*, ISBN 0-87629-504-9, pages 106-107 table 16 200 Conduits

[3] John H. Chiang, (Ed), *RS Means Electrical Cost Data 30th Annual Edition*, RSMeans Construction Publishers, Kingston MA USA, 2007, ISBN 0-87629-856-0

[4] Cauldwell 2002:109.

[5] Mini Trunking PVC White 25 × 16 mm

[6] "Wallduct Medical Raceway System". Retrieved 2014-10-04.

[7] "Wall Duct - Schneider Electric United States". Retrieved 2014-10-04.

[8] "Raceway Solutions - Wall" (PDF). Retrieved 2014-10-04.

[9] "Raceway & Wiring Ducts". Retrieved 2014-10-04.

[10] GR-356, *Generic Requirements for Optical Cable Innerduct, Associated Conduit, and Accessories*. Telcordia.

20.9 Bibliography

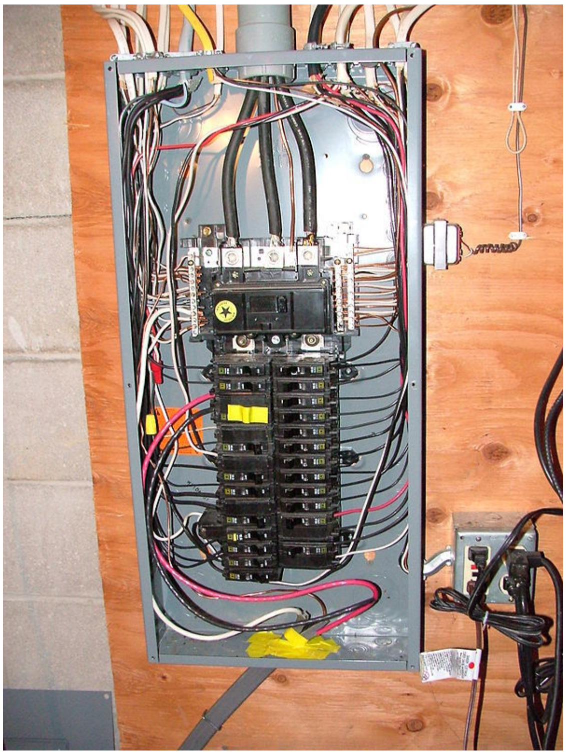
- Cauldwell, Rex (2002). *Wiring a House (For Pros By Pros)*. Newtown, CT, USA: Taunton Press. ISBN 1-56158-527-0.

20.10 External links

- Electrical Conduit and Wire Weight Calculator
- Conduit definition
- How to Bend Conduit Using a Pipe Bender
- Switch Boards Types

Chapter 21

Electrical wiring in North America



A typical circuit breaker box for a US home, with cover removed

Electrical wiring in North America follows regulations and standards for installation of building wiring.

21.1 Terminology

Although much of the electrician's field terminology matches that of the electrical codes, usages can vary.

- **Neutral** wire is the return conductor of a circuit; in building wiring systems, the neutral wire is connected to earth ground at least at one point. North American standards state that the neutral is neither switched nor fused except in very narrowly defined circumstances. The neutral is connected to the center tap of the power company transformer of a split-phase system, or the center of the wye connection of a polyphase power system.

  The United States electrical codes require that the neutral be connected to earth at the "service panel" only and at no other point within the building wiring system. Formally, the neutral is called the "grounded conductor"; as of the 2008 NEC, the terms "neutral conductor" and "neutral point" have been defined in the Code to record what had been common usage.[1]

- **Hot** is any conductor (wire or otherwise) connected with an electrical system that has electric potential relative to electrical ground or neutral.
- **Grounded** is a conductor with continuity to earth.[1]
- **Leg** as in "hot leg" refers to one of multiple **hot** conductors in an electrical system. The most common residential and small commercial service in Canada and the U.S., single split-phase, 240 V, features a neutral and two hot legs, 240 V to each other, and 120 V each to the neutral. The most common three-phase system will have three "hot" legs, 208 V to each other and 120 V each to the neutral. An older, but still widely used high-leg delta system uses three phases with 240 volts phase-to-phase for motor loads, and 120 volts for lighting loads by use of a center-tapped transformer; two of the phases are 120 volts to neutral. The third phase, the "high leg" of the system (also referred to as the "wild leg"), has 208 V to neutral and is not usually used for single-phase connections, so is distinctively colored. For larger commercial installations, 277/480 V or 347/600 V three phase is common.
- An **outlet** is called a receptacle in the NEC. In the NEC, an outlet is "a point in the wiring system at which current is taken to utilization equipment."[1]

21.2 Electrical codes and standards

The National Electrical Code (NEC) specifies acceptable wiring methods and materials for many states and municipalities in the U.S.[2] It is sponsored by the National Fire

Protection Association and has been periodically revised since 1897. Local jurisdictions usually adopt the NEC or another published code and then distribute documents describing how local codes vary from the published codes. Governments cannot distribute the NEC itself for copyright reasons, though parts that have been adopted into law are not subject to copyright.

The purpose of the NEC is to protect persons and property from hazards arising from the use of electricity. The NEC is not any jurisdiction's electrical code per se; rather, it is an influential work of standards that local legislators (e.g., city council members, state legislators, etc. as appropriate) tend to use as a guide when enacting local electrical codes. The NFPA states that excerpts quoted from the National Electrical Code must have a disclaimer indicating that the excerpt is not the complete and authoritative position of the NFPA and that the original NEC document must be consulted as the definitive reference.

New construction, additions or major modifications must follow the relevant code for that jurisdiction, which is not necessarily the latest version of the NEC. Regulations in each jurisdiction will indicate when a change to an existing installation is so great that it must then be rebuilt to comply with the current electrical code. Generally existing installations are not required to be changed to meet new codes.

Other code requirements vary by jurisdiction in the United States. In many areas, a homeowner, for example, can perform household wiring for a building which the owner occupies;[3] this may even be complete wiring of a home. A few cities[4] have more restrictive rules and require electrical installations to be done by licensed electricians. The work will be inspected by a designated authority at several stages before permission is obtained to energize the wiring from the local electric utility; the inspector may be an employee of the state or city, or an employee of an electrical supply utility.

For electrical wiring in Canada, the Canadian Electrical Code is a very similar standard published in Canada by the Canadian Standards Association since 1927.

21.3 Design and installation conventions

For residential wiring, some basic rules given in the NEC are:

- *Phase* wire in a circuit may be black, red, orange (high leg delta) insulated wire, sometimes other colors, but never green, gray, or white (whether these are solid colors or stripes). Specific exceptions apply, such as a cable running to a switch and back (known as a traveler) where the white wire will be the hot wire feeding that switch. Another is for a cable used to feed an outlet for 250VAC 15 or 20 amp appliances that do not need a neutral, there the white is hot (but should be identified as being hot, usually with black tape inside junction boxes).
- The *neutral* wire is identified by gray or white insulated wire, perhaps using stripes or markings.
- With lamp cord wire the ribbed wire is the neutral, and the smooth wire is the hot. NEC2008 400.22(f) allows surface marking with ridged, grooves or white stripes on the surface of lamp cord. With transparent cord the hot wire is copper colored, and the neutral is silver colored.
- *Grounding* wire of circuit may be bare or identified insulated wire of green or having green stripes. All metallic systems in a building are to be bonded to the building grounding system, such as water, natural gas, HVAC piping, and others.
- Larger wires are furnished only in black; these may be properly identified with suitable paint or tape.
- All wiring in a circuit except for the leads that are part of a device or fixture must be the same gauge. Different size wires may be used in the same raceway so long as they are all insulated for the maximum voltage of any of these circuits.
- The Code gives rules for calculating circuit loading.
- Ground-fault circuit interrupter (GFCI) protection is required on receptacles in wet locations. This includes all small appliance circuits in a kitchen, receptacles in a crawl space, basements, bathrooms and a receptacle for the laundry room, as well as outdoor circuits within easy reach of the ground. However, they are not required for refrigerators because unattended disconnection could cause spoilage of food, nor for garbage disposals. Instead, for refrigerators and other semi-permanent appliances in basements and wet areas, a one-outlet non-GFCI dedicated receptacle is generally used. Two-wire outlets having no grounding conductor may be protected by an upstream gfci and must be labelled "no grounding". Most GFCI receptacles allow the connection and have GFCI protection for down-stream connected receptacles. Receptacles protected in this manner should be labeled "GFCI protected". (Outside North America these are referred to as a "Residual-current device" or RCD.)
- Most circuits have the metallic components interconnected with a grounding wire connected to the third, round prong of a plug, and to metal boxes and appliance chassis.
- Furnaces, water heaters, heat pumps, central air conditioning units and stoves must be on dedicated circuits

- The code provides rules for sizing electrical boxes for the number of wires and wiring devices in the box.
- In a fixture, the brass screw is hot, and the silver screw is neutral. The grounding screw is usually painted green.

The foregoing is just a brief overview and must not be used as a substitute for the actual National Electrical Code.

21.4 Comparison of US practices with other countries

Electrical wiring practices developed in parallel in many countries in the late 19th and early 20th centuries.[5] As a result, national and regional variations developed and remain in effect. (see National Electrical Code, electrical wiring, electrical wiring in the United Kingdom). Some of these are retained for technical reasons, since the safety of wiring systems depends not only on the wiring code but also on the technical standards for wiring devices, materials, and equipment.

Grounding (earthing) of distribution circuits is a notable difference in practice between wiring systems of the United States and those of other regions. Since the early 1960s, wiring in new construction has required a separate grounding conductor used to bond (electrically connect) all normally non-current carrying parts of an electrical installation. Portable appliances with metal cases also have a bonding conductor in the flexible cable and plug connecting them to the distribution system. The circuit return conductor (*neutral*) is also connected to ground at the service entrance panel only; no other connections from neutral to ground are allowed, unlike regulations in other parts of the world.

Lighting and power receptacle circuits in North American systems are typically radial from a distribution panel containing circuit breakers to protect each branch circuit.[6] The smallest branch circuit rating is 15 amperes, used for general purpose receptacles and lighting. Often, 20 ampere circuits are used for general purpose receptacles and lighting. In residential construction, branch circuits for higher ratings are usually dedicated to one appliance, for example, fixed cooking appliances, electric clothes dryers, and air conditioners. Lighting and general purpose receptacles are at 120 volts AC, with larger devices fed by three wire single-phase circuits at 240 volts.

In commercial construction, three-phase circuits are used. Generally, receptacles are fed by 120 V or 208 V (in place of 240 V in a house), and can include special current rated outlets for industrial equipment. Lighting is usually fed by 277 V (with exception for special-use lights that use 120 V). Equipment can be hard-wired into the building using either 120/208 V or 277/480 V.

Countries such as Mexico may adopt the NFPA standard as their national electrical code, with local amendments similar to those in United States jurisdictions. The Canadian Electrical Code, while developed independently from the NFPA code, is similar in scope and intent to the US NEC, with only minor variations in technical requirement details; harmonization of the CEC and NEC codes is intended to facilitate free trade between the two countries.

21.5 Wiring methods

Romex type non-metallic sheathed cable

Most circuits in the modern North American home and light commercial construction are wired with non-metallic sheathed (NM) cable designated type (often referred to by the brand name "Romex").[7] This type of cable is the least expensive for a given size and is appropriate for dry indoor applications. The designation NM XX-Y indicates, respectively, the type of sheathing (in this case, non-metallic), the size of the main conductors, and the total number of circuit conductors (exclusive of the grounding conductor). For example, NM 14-2 cable contains three conductors (two plus one ground) at 14 gauge, a size typically used for circuits protected at 15 amperes. Circuits with larger currents (such as for electric furnaces, water heaters, air conditioners, or sub-mains to additional circuit panels) will have larger conductors. Not all US jurisdictions permit use of non-metallic sheathed cable. The NEC does not permit use of NM cable in large, fire-resistant, or high-rise structures.[8]

In type NM cable, conductor insulation is color-coded for identification, typically one black, one white, and a bare grounding conductor. The National Electrical Code (NEC) specifies that the black conductor represent the *hot* conductor, with significant voltage to earth ground; the white conductor represent the identified or neutral conductor, near ground potential;[9] and the bare/green conductor, the safety grounding conductor not normally used to carry circuit current. Wires may be re-coloured, so these rules are commonly excepted.[10] In 240-volt applications not requiring a neutral conductor, the white wire may be used as the second hot conductor, but must be recolored with tape or by some other method. Four-wire flexible equipment connection cords have red as the fourth color; unlike older European practices, color-coding in flexible cords is the same as for fixed wiring.

In commercial and industrial, unenclosed NM cable is often prohibited in certain areas or altogether (depending on what the building is used for and local/state building codes). Therefore, it is almost never used by commercial electrical contractors. Most wiring is put in non-flexible conduit, usually EMT because of its cost and durability. Rigid may be required for certain areas and additionally, vapor-lock fittings may be required in areas where a fire or explosion hazard is present (such as gas stations, chemical factories, grain silos, etc.) PVC can be used where wire is run underground or where concrete will be poured. A duct bank is usually made of multiple PVC conduits encased in concrete. FMC or Flex is used where EMT or other non-flexible conduit is impractical or for short runs, known as “whips”, to lights or other devices. For power circuits, the color-coding uses the same colors as residential construction, and adds the additional wires used for three-phase systems. Black, Red and Blue are used for hot wires and White is used as the neutral wire in a 120/208V circuit. Brown, Orange and Yellow are used as hot wires and gray is used as the neutral wire in a 277/480V. For grounding, regardless of the voltage, Green is used.

Several other types of wiring systems are used for building wiring in the United States; these include corrugated metal armored cable, mineral-insulated cable, other types of power cable, and various types of electrical conduit. In industrial applications cables may be laid in cable trays. Cable type TC is especially intended for use in tray systems. Special wiring rules apply to wet or corrosive locations,[11] and to locations which present an explosion hazard.[12] Wiring materials for use in the United States must generally be made and tested to product standards set by NEMA and Underwriters Laboratories (UL) and must bear approval marks such as those set by UL.

Approved wiring types can vary by jurisdiction. Not all wiring methods approved in the NEC are accepted in all areas of the United States.

21.6 Wire types

Wire types for North American wiring practices are defined by standards issued by Underwriters Laboratories, the Canadian Standards Association, the American Society for Testing and Materials, the National Electrical Manufacturers Association and the Insulated Cable Engineers Association.

XHHW stands for "**X**LPE (cross-linked polyethylene) **H**igh **H**eat-resistant **W**ater-resistant.”[13] XHHW is a designation for a specific insulation material, temperature rating, and condition of use (suitable for wet locations) for electrical wire and cable.[14]

Heavy duty outdoor electrical wire.

Wires with XHHW insulation are commonly used in the alternating current (AC) electrical distribution systems of commercial, institutional, and industrial buildings and installations, usually at voltage levels (potential difference or electromotive force) ranging from 110-600 volts. This type of insulation is used for both copper and aluminum conductors [15] which are either solid or stranded, depending on size.

According to Underwriters Laboratories (UL) Standard 44,[16] XHHW insulation is suitable for use in dry locations up to 90°C (194°F), or wet locations up to 75°C (167°F).

XHHW-2 insulation, which is similar to XHHW, is suitable for use in dry or wet locations up to 90°C (194°F).

THWN stands for "**T**hermoplastic **H**eat and **W**ater-resistant **N**ylon-coated.”[17] THWN is a designation for a specific insulation material, temperature rating, and condition of use (wet locations) for electrical wire and cable.[14]

Wires with THWN insulation are commonly used in the alternating current (AC) electrical distribution systems of buildings of all types and sizes throughout North America, usually at voltage levels (potential difference or electromotive force) ranging from 110-600 volts. This type of insulation is used for both copper and aluminum conductors [15] which are either solid or stranded, depending on size.

THHN stands for "**T**hermoplastic **H**igh **H**eat-resistant **N**ylon-coated.”[18] THHN is a designation for a specific insulation material, temperature rating, and condition of use (suitable for dry and damp locations) for electrical wire and cable.[14]

Wire with THHN insulation is commonly used in the alternating current (AC) electrical distribution systems of all types and sizes throughout North America, usually at voltage levels (potential difference or electromotive force) ranging from 110-600 volts. This type of insulation is used for both copper and aluminum conductors [15] which are either solid or stranded, depending on size.

Many wires are rated both THWN and THHN, and are suitable for use in dry locations up to 90°C (194°F), or wet locations up to 75°C (167°F).

21.7 See also

- American wire gauge
- Twist-on wire connector

21.8 References

[1] *National Electric Code*. National Fire Protection Association. 2008. p. 100. ISBN 978-0-87765-791-0.

[2] Edward R. Lipinski (January 19, 1997), *Electrical Codes and Regulations* (&NDASH; SCHOLAR SEARCH), New York Times

[3] http://weststpaul.govoffice.com/vertical/Sites/%7B2CF6FEAE-EDC4-4E50-A078-817B219E41B8%7D/uploads/%7B3186FAFA-5503-46B8-AEFD-2206DE693396%7D.PDF City of West St. Paul Electrical Inspections information sheet retrieved 2008 feb 10

[4] http://www.ci.nyc.ny.us/html/dob//html/applications_and_permits/electrical_permit_and_insp.shtml New York Electrical permits, retrieved 2008 Feb 10. The city of New York, for example requires all installation work to be done by licensed contractors

[5] R. M. Black *The History of Electric Wires and Cables*, Peter Pergrinus, London 1983 ISBN 0-86341-001-4

[6] American Electrician's Handbook page 9-87

[7] Terrell Croft and Wilford Summers (ed), *American Electrican's Handbook, Eleventh Edition*, McGraw Hill, New York (1987) ISBN 0-07-013932-6 page 9-86

[8] *National Electric Code*. National Fire Protection Association. 2008. p. 334.10. ISBN 978-0-87765-791-0.

[9] *National Electric Code*. National Fire Protection Association. 2008. p. 200.7. ISBN 978-0-87765-791-0.

[10] *National Electric Code*. National Fire Protection Association. 2008. p. 200.6(A). ISBN 978-0-87765-791-0.

[11] *National Electric Code*. National Fire Protection Association. 2008. p. 110.11. ISBN 978-0-87765-791-0.

[12] *National Electric Code*. National Fire Protection Association. 2008. p. 500. ISBN 978-0-87765-791-0.

[13] What does XHHW stand for? Acronym Finder Definition

[14] NFPA 70 National Electrical Code (NEC) 2008 edition, Article 310.8 (B)&(C), Table 310.13(A)

[15] NFPA 70 National Electrical Code (NEC) 2008 edition, Article 310.14

[16] Scope for UL 44

[17] What does THWN stand for? Acronym Finder Definition

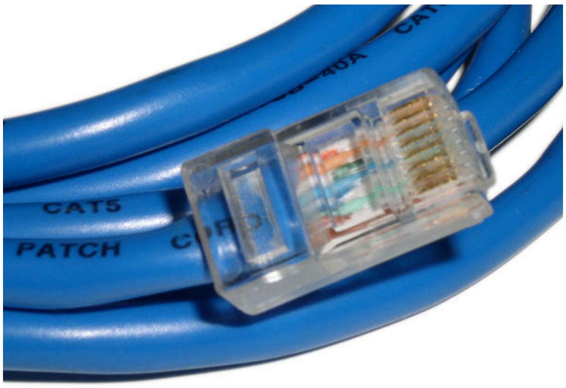
[18] What does THHN stand for? Acronym Finder Definition

21.9 External links

- The NEC at NFPA.org
- Summary of NEC Color Code

Chapter 22

Category 5 cable



Category 5 patch cable in T568B wiring

Category 5 cable (**cat 5**) is a twisted pair cable for carrying signals. This type of cable is used in structured cabling for computer networks such as Ethernet. The cable standard provides performance of up to 100 MHz and is suitable for 10BASE-T, 100BASE-TX (Fast Ethernet), and 1000BASE-T (Gigabit Ethernet). Cat 5 is also used to carry other signals such as telephony and video.

This cable is commonly connected using punch-down blocks and modular connectors. Most category 5 cables are unshielded, relying on the balanced line twisted pair design and differential signaling for noise rejection.

Category 5 has been superseded by the **category 5e** (enhanced) specification [1] and category 6 cable.

22.1 Cable standard

The specification for category 5 cable was defined in ANSI/TIA/EIA-568-A, with clarification in TSB-95.[3] These documents specify performance characteristics and test requirements for frequencies up to 100 MHz. Cable types, connector types and cabling topologies are defined by TIA/EIA-568-B. Nearly always, 8P8C modular connectors, often referred to as RJ45, are used for connecting category 5 cable. The cable is terminated in either the T568A scheme or the T568B scheme. The two schemes work equally well and may be mixed in an installation so long as the same scheme is used on both ends of each cable.

Each of the four pairs in a cat 5 cable has differing precise number of twists per metre to minimize crosstalk between the pairs. Although cable assemblies containing 4 pairs are common, category 5 is not limited to 4 pairs. Backbone applications involve using up to 100 pairs.[4] This use of balanced lines helps preserve a high signal-to-noise ratio despite interference from both external sources and crosstalk from other pairs.

The cable is available in both stranded and solid conductor forms. The stranded form is more flexible and withstands more bending without breaking. Permanent wiring (for example, the wiring inside the wall that connects a wall socket to a central patch panel) is solid-core, while patch cables (for example, the movable cable that plugs into the wall socket on one end and a computer on the other) are stranded.

The specific category of cable in use can be identified by the printing on the side of the cable.[5]

22.1.1 Bending radius

Most Category 5 cables can be bent at any radius exceeding approximately four times the outside diameter of the cable.[6][7]

22.1.2 Maximum cable segment length

The maximum length for a cable segment is 100 m per TIA/EIA 568-5-A.[8] If longer runs are required, the use of active hardware such as a repeater or switch is necessary.[9][10] The specifications for 10BASE-T networking specify a 100-metre length between active devices.[11] This allows for 90 metres of solid-core permanent wiring, two connectors and two stranded patch cables of 5 metres, one at each end.[12]

22.1.3 Category 5 vs. 5e

To support Gigabit Ethernet, a higher performance version of cat 5, enhanced cat 5 or cat 5e has been added to the standards. Cat 5e adds new performance requirements to permit higher speed network operation.[13][14]

The category 5e specification improves upon the category 5 specification by tightening some crosstalk specifications and introducing new crosstalk specifications that were not present in the original category 5 specification. The bandwidth of category 5 and 5e is the same – 100 MHz.

The differences between category 5 and category 5e are in their transmission performance. Category 5e components are most suitable for a high-speed Gigabit Ethernet. While category 5 components may function to some degree in a Gigabit Ethernet, they perform below standard during high-data transfer scenarios.

22.2 Applications

This type of cable is used in structured cabling for computer networks such as Ethernet over twisted pair. The cable standard provides performance of up to 100 MHz and is suitable for 10BASE-T, 100BASE-TX (Fast Ethernet), and 1000BASE-T (Gigabit Ethernet). 10BASE-T and 100BASE-TX Ethernet connections require two wire pairs. 1000BASE-T Ethernet connections require four wire pairs. Through the use of power over Ethernet (PoE), up to 25 watts of power can be carried over the cable in addition to Ethernet data.

Cat 5 is also used to carry other signals such as telephony and video.[15]

22.2.1 Shared cable

In some cases, multiple signals can be carried on a single cable; cat 5 can carry two conventional telephone lines as well as 100BASE-TX in a single cable.[16][17][18][19][20] The USOC/RJ-61 wiring standard may be used in multi-line telephone connections.

Various schemes exist for transporting both analog and digital video over the cable. HDBaseT (10.2 Gbit/s) is one such scheme.[21]

22.3 Characteristics

22.3.1 Insulation

Outer insulation is typically PVC or LSOH.

22.3.2 Conductors

Since 1995, solid-conductor UTP cables for backbone cabling is required to be no thicker than 22 American Wire Gauge (AWG) and no thinner than 24 AWG, or 26 AWG for shorter-distance cabling. This standard has been retained with the 2009 revision of ANSI TIA/EIA 568.[27]

22.3.3 Individual twist lengths

By altering the length of each twist, crosstalk is reduced, without affecting the characteristic impedance. The distance per twist is commonly referred to as pitch. The pitch of the twisted pairs is not specified in the standard. Measurements on one sample of cat 5 cable yielded the following results.[28]

22.3.4 Environmental ratings

> CMR (**Com**munications **R**iser), insulated with high-density polyolefin and jacketed with low-smoke polyvinyl chloride (PVC).
>
> CMP (**Com**munications **P**lenum), insulated with fluorinated ethylene propylene (FEP) and polyethylene (PE) and jacketed with low-smoke polyvinyl chloride (PVC), due to better flame test ratings.
>
> CM (**Com**munications) is insulated with high-density polyolefin, but not jacketed with PVC and therefore is the lowest of the three in flame resistance.

Some cables are "UV-rated" or "UV-stable" meaning they can be exposed to outdoor UV radiation without significant destruction. The materials used for the mantle are usually PVC.[31]

Any cable that contains air spaces can breathe in moisture, especially if the cable runs between indoor and outdoor spaces. Warm moist air can cause condensation inside the colder parts of the cable outdoors. It may be necessary to take precautions such as sealing the ends of the cables. Some cables are suitable for "direct burial", but this usually requires that the cable be gel filled in order to hinder moisture migration into the cable.

When using a cable for a tower, attention must be given to vertical cable runs that may channel water into sensitive indoor equipment.[32] This can often be solved by adding a drip-loop at the bottom of the run of cable. If water enters the cable over a long time, for example a break in the outer shield due to wind movement fatigue, this can set up substantial head pressure within the cable. Water ingress at 28m can induce a pressure of 40 psi forcing water many meters along a horizontal run including back upwards. Therefore it is imperative to maintain the integrity of the outer sheath on tall towers.

Plenum-rated cables are slower to burn and produce less smoke than cables using a mantle of materials like PVC. This also affects legal requirements for a fire sprinkler system. That is if a plenum-rated cable is used, sprinkler requirement may be eliminated.[33]

Shielded cables (FTP/STP) are useful for environments where proximity to RF equipment may introduce electromagnetic interference, and can also be used where eavesdropping likelihood should be minimized.

22.4 See also

- American wire gauge (AWG)
- Audio over Ethernet (AoE)
- Category 6 cable
- Ethernet over twisted pair (10/100/1000BASE-T)
- Power over Ethernet (PoE)

22.5 Notes

22.6 References

[1] "Voice and Data Cabling & Wiring Installations". Retrieved 2013-05-12.

[2] "ANSI/TIA/EIA-568-B.1-2001 Approved: April 12, 2001 ; Commercial Building Telecommunications Cabling Standard Part 1: General Requirements" (PDF). 090917 nag.ru

[3] "Additional Transmission Performance Guidelines for 4-pair 100 v category 5 Cabling" (PDF). Retrieved 2013-05-12.

[4] As noted in ANSI/TIA/EIA-568-B-2 standard for backbone applications

[5] "Ethernet Cable Identification and Use". Donutey. Retrieved 2011-04-01.

[6] "Selecting coax and twisted-pair cable". Electronic Products.

[7] "Category 5". Retrieved 2013-05-12.

[8] "The Evolution of Copper Cabling Systems from Cat5 to Cat5e to Cat6" (PDF). Panduit. 2004-02-27. Retrieved 2013-05-12.

[9] "UTP technology" (PDF). Extron Electronics. 2001. Retrieved 2013-05-12.

[10] "CAT5e Cable Wiring Schemes". B&B Electronics. Archived from the original on 2012-10-05.

[11] "IEEE Std 802.3-2008". Institute of Electrical and Electronics Engineers. 2008. Table 13-1

[12] "Horizontal Cabling". The Network Encyclopedia. Retrieved 2013-05-12.

[13] "UNDERSTANDING CAT - 5 CABLES" (PDF). Satelliete & Cable TV. Retrieved 2013-01-05

[14] "Cat5 Spec, cat6 specs, cat7 spec - Definitions, Comparison, Specifications". TEC Datawire. Retrieved 2013-01-05

[15] "Transmitting video over CAT5 cable". EE Times. 2005-06-08. Retrieved 2013-12-07

[16] "Hack your House: Run both ethernet and phone over existing Cat-5 cable". Retrieved 2013.

[17] ZyTrax. "LAN and Telephones". quote: "Since 10base-T or 100base-TX wiring uses 2 pairs (4 wires) and each analog phone connection uses a single pair (2 wires) you can, subject to limitations, run 2 telephone connections and LAN traffic on category 5(e) wiring"

[18] Siemon. "Cable Sharing in Commercial Building Environments: Reducing Cost, Simplifying Cable Management, and Converging Applications onto Twisted-Pair Media". retrieved 2014-04-28.

[19] "RJ45/RJ11 Network Cable Splitters for Ethernet and Phone Line Sharing". quote: "carry one old fashioned analog telephone signal and one 10/100Mbps Ethernet signal by the same single network cable."

[20] "ATS 10/100 Base T Splitter Adapters". Duxcw.com. Retrieved 2014-08-17.

[21] "HDBaseT Alliance Shows the Future of Connected Home Entertainment at CES 2013" (PDF). *News release*. January 9, 2013. Retrieved June 5, 2013.

[22] "SuperCat OUTDOOR CAT 5e U/UTP" (PDF). Archived from the original (PDF) on 2012-03-16.

[23] "Transmission Line Zo".

[24] "Wire Gauge and Current Limits Including Skin Depth and Strength". PowerStream. Retrieved 2013-05-12.

[25] IEEE 802.3at-2009 Table 33-11

[26] "Copper Data Cables" (PDF). p. 6. Archived from the original (PDF) on 2006-06-25.

[27] "ANSI/TIA/EIA-568-B.2-2001, Commercial Building Telecommunications Cabling Standard" (PDF). p. 6 ¶4.3.2.

[28] http://www.prc68.com/I/Zo.shtml#Wm

[29] "Technical Information" (PDF). Belden. p. 22.20. Archived from the original (PDF) on 2012-03-03.

[30] "CSA Flame Test Ratings". Retrieved 2013-05-12.

[31] "CAT5e CMR/CMX mean it's uv rated?". Retrieved 2009-01-26.

[32] "A dumb mistake a green WISP operator once made.". Retrieved 2009-01-26.

[33] "What are the differences between PVC, riser and plenum-rated cables?". Retrieved 2009-01-26.

Chapter 23

Category 6 cable

A Cat 6 ethernet cable

Category 6 cable, commonly referred to as **Cat 6**, is a standardized cable for Gigabit Ethernet and other network physical layers that is backward compatible with the Category 5/5e and Category 3 cable standards.[1] Compared with Cat 5 and Cat 5e, Cat 6 features more stringent specifications for crosstalk and system noise.[1] The cable standard provides performance of up to 250 MHz and is suitable for 10BASE-T, 100BASE-TX (Fast Ethernet), 1000BASE-T/1000BASE-TX (Gigabit Ethernet), and 10GBASE-T (10-Gigabit Ethernet).[1]

23.1 Description

Whereas Category 6 cable has a reduced maximum length when used for 10GBASE-T, **Category 6A cable** (or **Augmented Category 6**) is characterized to 500 MHz and has improved alien crosstalk characteristics, allowing 10GBASE-T to be run for the same 100 meter distance as previous Ethernet variants.

Category 6 cable can be identified by the printing on the side of the cable sheath.[2]

Cat 6 patch cables are normally terminated in 8P8C modular connectors. If Cat 6 rated patch cables, jacks and connectors are not used with Cat 6 wiring, overall performance is degraded and will not meet Cat 6 performance specifications.[3]

Connectors use either T568A or T568B pin assignments; although performance is comparable provided both ends of a cable are the same.

23.2 Category 6A

The latest standard from the TIA for enhanced performance standards for twisted pair cable systems was defined in February 2009 in ANSI/TIA-568-C.1. Category 6A is defined at frequencies up to 500 MHz—twice that of Cat 6.

Category 6A performs at improved specifications, in particular in the area of alien crosstalk as compared to Cat 6 UTP (unshielded twisted pair), which exhibited high alien noise in high frequencies.

The global cabling standard ISO/IEC 11801 has been extended by the addition of amendment 2. This amendment defines new specifications for Cat 6A components and Class EA permanent links. These new global Cat 6A/Class EA specifications require a new generation of connecting hardware offering far superior performance compared to the existing products that are based on the American TIA standard.[4]

The most important point is a performance difference between ISO/IEC and EIA/TIA component specifications for the NEXT transmission parameter. At a frequency of 500 MHz, an ISO/IEC Cat 6A connector performs 3 dB better than a Cat 6A connector that conforms with the EIA/TIA specification. 3 dB equals 50% reduction of near-end crosstalk noise signal power; see 3dB-point.[4]

Confusion therefore arises because of the different naming conventions and performance benchmarks laid down by the International ISO/IEC and American TIA/EIA standards, which in turn are different from the regional European standard, EN 50173-1. In broad terms, the ISO standard for Cat 6A is the highest, followed by the European standard, and then the American (1 on 1 matching capability).[5][6]

23.3 Maximum length

When used for 10/100/1000BASE-T, the maximum allowed length of a Cat 6 cable is 100 meters (328 ft). This consists of 90 meters (295 ft) of solid "horizontal" cabling between the patch panel and the wall jack, plus 10 meters (33 ft) of stranded patch cable between each jack and the attached device.

When used for 10GBASE-T, Cat 6 cable's maximum length is 55 meters (180 ft) in a favorable alien crosstalk environment, but only 33 meters (108 ft) in a hostile alien crosstalk environment, such as when many cables are bundled together. However, because the effects of alien crosstalk environments on cables are difficult to determine prior to installation, it is highly recommended that all Cat 6 cables used for 10GBASE-T be electrically tested once installed. With its improved specifications, Cat 6A does not have this limitation and can run 10GBASE-T at 100 meters (328 ft) without electronic testing.

23.4 Installation caveats

Category 6 and 6A cable must be properly installed and terminated to meet specifications. The cable must not be kinked or bent too tightly (the bend radius should be at least four times the outer diameter of the cable[7]). The wire pairs must not be untwisted and the outer jacket must not be stripped back more than 0.5 in (12.7 mm).

Cable shielding may be required in order to improve a Cat 6 cable's performance in high electromagnetic interference (EMI) environments. This shielding reduces the corrupting effect of EMI on the cable's data. Shielding is typically maintained from one cable end to the other using a drain wire that runs through the cable alongside the twisted pairs. The shield's electrical connection to the chassis on each end is made through the jacks. The requirement for ground connections at both cable ends creates the possibility that a ground loop may result if one of the networked chassis is at different instantaneous electrical potential with respect to its mate. This undesirable situation may compel currents to flow between chassis through the network cable shield, and these currents may in turn induce detrimental noise in the signal being carried by the cable.

23.5 Category 6e

Following the finalization of Cat 6, a number of manufacturers began offering "Category 6e" cables as an enhancement to the Category 6 standard—presumably naming it after Category 5e. However, no legitimate Category 6e standard exists,[8] and Cat 6e is not a recognized standard by the Telecommunications Industry Association.

While all Cat 6e cables presumably meet Category 6 standards, the actual increase in transfer speeds, if any, and the maximum cable length can vary from manufacturer to manufacturer owing to the lack of a recognized industry standard.

23.6 See also

- Ethernet crossover cable

23.7 References

[1] Kish, Paul (July 2002). "Category 6 Cabling Questions and Answers" (PDF). NORDX/CDT, Inc. Retrieved 21 October 2013.

[2] Ethernet Cable Identification and Use

[3] ANSI/TIA/EIA 568-B.2-1

[4] "A new Category 6A specification has arrived". *Next generation Cat. 6A*. Tyco Electronics. Retrieved 2011-03-22.

[5] "Cat. 6A ≠ Cat. 6 A ≠ Class EA". *Next generation Cat. 6A*. Tyco Electronics. Retrieved 2011-03-22.

[6] Cabling: The Complete Guide to Network Wiring, 3rd Edition

[7] "Category 5 / 5E & Cat 6 Cabling Tutorial and FAQ's". LANshack.com. Retrieved 2012-01-06.

[8] Cat 6e vs Cat 6a

23.8 External links

- "10 Gb/s Over Copper: Horizontal Cabling Choices". The Siemon Company. 2006-01-10. Retrieved 2015-02-13. Information on cable construction and alien crosstalk mitigation.
- Schmidt, John (March–April 2007). "Determining the Right Media" (PDF). *BICSI News* **28** (2). Archived from the original (PDF) on 2010-01-04. Information on TIA TSB-155 37m versus IEEE 55m limitations.
- "How to Make an Ethernet Cat5e/Cat6 Cable". Cable & Wireless Technologies, Inc. 2009-10-14. Retrieved 2015-02-13.
- "How to Terminate Cat6a Shielded Keystone Jacks". Cable & Wireless Technologies, Inc. 2009-12-09. Retrieved 2015-02-13.
- "How Category 6 Cable is Made". Cable & Wireless Technologies, Inc. 2009-11-05. Retrieved 2015-02-13.
- "What Really Changes With Category 6". The Siemon Company. Retrieved 2013-01-05.

Chapter 24

ISO/IEC 11801

International standard **ISO/IEC 11801** *Information technology — Generic cabling for customer premises* specifies general-purpose telecommunication cabling systems (structured cabling) that are suitable for a wide range of applications (analog and ISDN telephony, various data communication standards, building control systems, factory automation). It covers both balanced copper cabling and optical fibre cabling.

The standard was designed for use within commercial premises that may consist of either a single building or of multiple buildings on a campus. It was optimized for premises that span up to 3 km, up to 1 km^2 office space, with between 50 and 50,000 persons, but can also be applied for installations outside this range.

A major revision, Edition 3, is being prepared which will unify requirements for commercial, home and industrial networks.

24.1 Classes and categories

The standard defines several link/channel classes and cabling categories of twisted-pair copper interconnects, which differ in the maximum frequency for which a certain channel performance is required:

- Class A: link/channel up to 100 kHz using Category 1 cable/connectors
- Class B: link/channel up to 1 MHz using Category 2 cable/connectors
- Class C: link/channel up to 16 MHz using Category 3 cable/connectors
- Class D: link/channel up to 100 MHz using Category 5e cable/connectors
- Class E: link/channel up to 250 MHz using Category 6 cable/connectors
- Class EA: link/channel up to 500 MHz using Category 6A cable/connectors (Amendment 1 and 2 to ISO/IEC 11801, 2nd Ed.)
- Class F: link/channel up to 600 MHz using Category 7 cable/connectors
- Class FA: link/channel up to 1000 MHz using Category 7A cable/connectors (Amendment 1 and 2 to ISO/IEC 11801, 2nd Ed.)
- Class I: link/channel up to between 1600 MHz and 2000 MHz using Category 8.1 cable/connectors (specification under development)
- Class II: link/channel up to between 1600 MHz and 2000 MHz using Category 8.2 cable/connectors (specification under development)

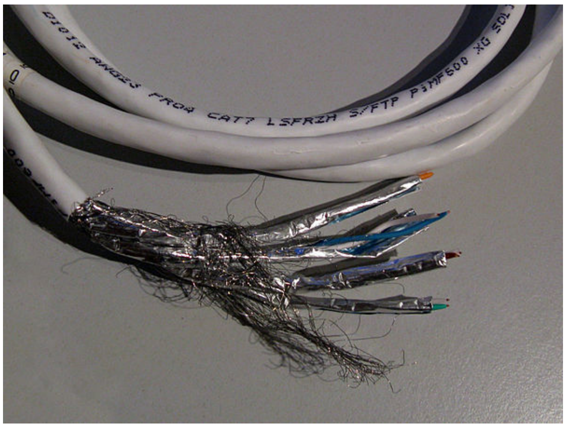
The standard link impedance is 100 Ω. (The older 1995 version of the standard also permitted 120 Ω and 150 Ω in Classes A−C, but this was removed from the 2002 edition.)

The standard defines several classes of optical fiber interconnect:

- OM1: Multimode fiber type 62.5 µm core; minimum modal bandwidth of 200 MHz*km at 850 nm
- OM2: Multimode fiber type 50 µm core; minimum modal bandwidth of 500 MHz*km at 850 nm
- OM3: Multimode fiber type 50 µm core; minimum modal bandwidth of 2000 MHz*km at 850 nm
- OM4: Multimode fiber type 50 µm core; minimum modal bandwidth of 4700 MHz*km at 850 nm
- OS1: Single-mode fiber type 1db/km attenuation
- OS2: Single-mode fiber type 0.4db/km attenuation

24.1.1 Class F

Class F channel and **Category 7** cable are backward compatible with Class D / Category 5e and Class E/Category 6. Class F features even stricter specifications for crosstalk and system noise than Class E. To achieve this, shielding has been added for individual wire pairs and the cable as a whole. Besides the shield, the twisting of the pairs and number of turns per unit length increases RF shielding and protects from crosstalk.



Category 7 S/FTP cable

The Category 7 cable standard has been created to allow 10 Gigabit Ethernet over 100 m of copper cabling (also, 10 Gbit/s Ethernet now is typically run on Cat 6A). The cable contains four twisted copper wire pairs, just like the earlier standards. Category 7 cable can be terminated either with 8P8C compatible GG45 electrical connectors which incorporate the 8P8C standard or with TERA connectors. When combined with GG45 or TERA connectors, Category 7 cable is rated for transmission frequencies of up to 600 MHz.[1]

As of November 2010, all manufacturers of active equipment have chosen to support the 8P8C for their 10 Gigabit Ethernet products on copper and not the GG45, ARJ45, or TERA in order to function on Cat 6A.

Category 7 is not recognized by the TIA/EIA.

24.1.2 Class FA

Class FA (Class F Augmented) channels and **Category 7A** cables, introduced by ISO 11801 Edition 2 Amendment 2 (2010), are defined at frequencies up to 1000 MHz, suitable for multiple applications including CATV (862 MHz). Each pair offers 1200 MHz of bandwidth.

Simulation results have shown that 40 Gigabit Ethernet may be possible at 50 meters (164 ft) and 100 Gigabit Ethernet at 15 meters (49 ft). In 2007, researchers at Pennsylvania State University predicted that either 32 nm or 22 nm circuits would allow for 100 Gigabit Ethernet at 100 meters(328 ft).[2][3]

Category 7A is not recognized in TIA/EIA-568.

24.1.3 Category 8

In March 2013, technical recommendation ISO/IEC TR 11801-99-1,[4][5][6] issued by ISO/IEC JTC 1 computer interconnect and premises cabling group SC25 WG3, defined two new categories for 4-pair copper twisted pair cable with 2 connectors, with operating frequency up to 1.6 GHz and possible overhead for 2.0 GHz:[7]

- **Class I** channel (**Category 8.1** cable): minimum cable design U/FTP or F/UTP, fully backward compatible and interoperable with Class EA (Category 6A) using 8P8C connectors
- **Class II** channel (**Category 8.2** cable): F/FTP or S/FTP minimum, interoperable with Class FA (Category 7A) using 8P8C or TERA/GG45/ARJ45 connectors

Also in March 2013, technical recommendation TIA TR42.7 defined that 40GBASE-T will require a new cabling system defined to at least 1.6 GHz and up to 2 GHz, currently called **Category 8**, which will use the standard 8P8C connector.[8] Category 8 should be fully backward compatible with Category 6A and below, and will be covered by ANSI/TIA-568-C.2-1 “Specifications for 100Ω Category 8 Cabling”.[9]

As of January 2014, draft versions of ISO/IEC TR 11801-99-1 and ANSI/TIA-568-C.2-1 have been aligned to reduce the difference between Categories 8, 8.1 and 8.2.[6] The final specifications will depend on transceiver requirements to be defined by IEEE 802.3bq workforce.[7]

24.2 Acronyms for twisted pairs

Main article: Twisted pair § Cable shielding

Annex E, *Acronyms for balanced cables*, provides a system to specify the exact construction for both unshielded and shielded balanced twisted pair cables. It uses three letters - U for unshielded, S for braided shielding, and F for foiled shielding - to form a two-part abbreviation in the form of xx/xTP, where the first part specifies the type of overall cable shielding, and the second part specifies shielding for individual cable elements.

Common cable types include U/UTP (unshielded cable); U/FTP (individual pair shielding without the overall screen); F/UTP, S/UTP, or SF/UTP (overall screen without individual shielding); and F/FTP or S/FTP (overall screen with individual foil shielding).

24.3 Edition 3

Edition 3, currently being prepared by ISO/IEC JTC 1/SC 25 “Interconnection of information technology equipment”, is a major revision of the standard which will unify several prior standards for commercial, home, and industrial networks, as well as data centers, and define requirements for generic cabling and distributed building networks.

The new series of standards will include six parts: [4] [10] [11] [12]

24.4 Versions

- ISO/IEC 11801:1995 (Ed. 1) - first edition
- ISO/IEC 11801:2000 (Ed. 1.1) - Edition 1, Amendment 1
- ISO/IEC 11801:2002 (Ed. 2) - second edition
- ISO/IEC 11801:2008 (Ed. 2.1) - Edition 2, Amendment 1
- ISO/IEC 11801:2010 (Ed. 2.2) - Edition 2, Amendment 2
- ISO/IEC 11801 Ed.3 (in development)

24.5 See also

- Ethernet over twisted pair
- Twisted pair
- TIA/EIA-568
- ISO/IEC JTC 1/SC 25

24.6 References

[1] Nielsen, Allan (2008), *AMP NETCONNECT Guide to ISO/IEC 11801 2nd Edition Including Amendment 1* (PDF), Schaffhausen, Switzerland: Tyco Electronics, p. 11, retrieved March 11, 2012

[2] "Researchers push transmission rate of copper cables". *News release* (Pennsylvania State University). November 14, 2007. Retrieved July 9, 2011.

[3] Rick C. Hodgin (November 14, 2007). "UPDATE: Cat-7 copper theorized to transmit 100 Gbit/s in excess of 100 meters (328 ft) using future modems". *TGDaily blog*. Retrieved July 9, 2011.

[4] Flatman, Alan (2013-05-16). "ISO/IEC TR 11801-99-1: Guidance on 40GBASE-T Cabling -a tutorial-" (PDF). Retrieved 2014-01-26.

[5] Flatman, Alan (2013-11-11). "Update on ISO/IEC 11801-99-1 Guidance on 40GBASE-T Cabling" (PDF). Retrieved 2014-07-09.

[6] Flatman, Alan (2014-01-23). "Update on ISO/IEC 11801-99-1 40GBASE-T Cabling Guidelines" (PDF). Retrieved 2014-07-09.

[7] http://www.knxtraining.gr/uploads/8/2/1/2/8212652/davidebadiali_bicsigreece_oct2013_rev002.pdf

[8] Sullivan, Ed (2013-05-01). "How Cat 8 cable will economically solve data centers' need for high bandwidth". Cabling Installation & Maintenance. Retrieved 2014-01-01.

[9] http://www.rdm.com/en/co/media/40gbase-t-a-quantum-leap-forward-for-data-centers.aspx

[10] http://www.commscope.com/Docs/StdsAdvisor_Q3-2013.pdf

[11] http://www.commscope.com/Docs/StdsAdvisor_Q1-2014.pdf

[12] http://www.commscope.com/docs/stdsadvisor_q2-2014.pdf

- International standard ISO/IEC 11801: Information technology — Generic cabling for customer premises.
- European standard EN 50173: Information technology — Generic cabling systems. 1995.

24.7 External links

- ГОСТ Р53246-2008

Chapter 25

Cross-linked polyethylene

“PEX” redirects here. For other uses, see Pex (disambiguation).

Cross-linked polyethylene, commonly abbreviated **PEX** or **XLPE**, is a form of polyethylene with cross-links. It is formed into tubing, and is used predominantly in building services pipework systems, hydronic radiant heating and cooling systems, domestic water piping, and insulation for high tension (high voltage) electrical cables. It is also used for natural gas and offshore oil applications, chemical transportation, and transportation of sewage and slurries.

In the 21st century, PEX has become a viable alternative to polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC) or copper tubing for use as residential water pipes. PEX tubing ranges in size from imperial sizes of 1/4-inch to 4-inch, but 1/2-inch, 3/4-inch, and 1-inch are by far the most widely used.[1] Metric PEX is normally available in 16 mm, 20 mm, 25 mm, 32 mm, 40 mm, 50 mm and 63 mm sizes.

25.1 Properties

Almost all PEX used for pipe and tubing is made from high density polyethylene (HDPE). PEX contains cross-linked bonds in the polymer structure, changing the thermoplastic to a thermoset. Cross-linking is accomplished during or after the extrusion of the tubing. The required degree of cross-linking, according to ASTM Standard F876, is between 65 and 89%. A higher degree of cross-linking could result in brittleness and stress cracking of the material while a lower degree of cross-linking could result in product with poorer physical properties.

Crosslinking improves the elevated-temperature properties of the base polymer. Adequate strength to 120–150 °C is maintained by reducing creep, the tendency to flow. Chemical resistance is enhanced by resisting dissolution. Low temperature properties are improved. Impact and tensile strength, scratch resistance, and resistance to brittle fracture are enhanced.

Almost all cross-linkable polyethylene compounds (XLPE) for wire and cable applications are based on LDPE. XLPE-insulated cables have a rated maximum conductor temperature of 90 °C and an emergency rating up to 140 °C, depending on the standard used. They have a conductor short-circuit rating of 250 °C. XLPE has excellent dielectric properties, making it useful for medium voltage—10 to 50 kV AC, and high voltage cables—up to 380 kV AC-voltage, and several hundred kV DC.

Numerous modifications in the basic polymer structure can be made to maximize productivity during the manufacturing process. For medium voltage applications, reactivity can be boosted significantly. This results in higher line speeds in cases where limitations in either the curing or cooling processes within the continuous vulcanization (CV) tubes used to cross-link the insulation. XLPE insulations can be modified to limit the amount of by-product gases generated during the cross-linking process. This is particularly useful for high voltage cable and extra-high voltage cable applications, where degassing requirements can significantly lengthen cable manufacturing time.

25.2 Preparation methods

The first PEX material was prepared in the 1930s, by irradiating the extruded tube with an electron beam. The electron beam processing method was made feasible in the 1970s but was still expensive. In the 1960s, Engel cross-linking was developed. In this method, a peroxide is mixed with the HDPE before extruding, the cross-linking taking place during the passage of the melted polymer through a long heated die. In 1968, the Sioplas process using silane was patented, followed by another silane-based process, Monosil, in 1974. A process using vinylsilane followed in 1986.

25.3 Classification

25.3.1 North America

Materials used in PEX pipes in North America are defined by cell classifications that are described in ASTM standards, the most common being ASTM F876. Cell classifications for PEX include 0006, 0008, 1006, 1008, 3006, 3008, 5006 and 5008, the most common being 5006. Classifications 0306, 3306, 5206 and 5306 are also common, these materials containing ultraviolet blockers and/or inhibitors for limited UV resistance. In North America all PEX tubing products are manufactured to ASTM, NSF and CSA product standards, among them the aforementioned ASTM standard F876 as well as F877, NSF International standards NSF 14 and NSF 61 ("NSF-pw"), and Canadian Standards Association standard B137.5, to which the pipes are tested, certified and listed. The listings and certifications met by each product appear on the printline of the pipe or tubing to ensure the product is used in the proper applications for which it was designed.

25.3.2 Europe

In European standards there are three classifications are referred to as PEX-A, -B, and -C. The classes are not related to any type of rating system.

PEX-A (PE-Xa, PEXa)

PEX-A is produced by the peroxide (Engel) method. This method performs "hot" cross-linking, above the crystal melting point. However, the process takes slightly longer than the other two methods as the polymer has to be kept at high temperature and pressure for long periods during the extrusion process. The cross-linked bonds are between carbon atoms.

PEX-B (PE-Xb, PEXb)

The silane method, also called the "moisture cure" method, results in PEX-B. In this method, cross-linking is performed in a secondary post-extrusion process, producing cross-links between a cross-linking agent. The process is accelerated with heat and moisture. The cross-linked bonds are formed through silanol condensation between two grafted vinyltrimethoxysilane (VTMS) units, connecting the polyethylene chains with C-C-Si-O-Si-C-C bridges. After installation, PEX-B have the same properties as PEX-A.

PEX-C (PE-Xc, PEXc)

PEX-C is produced through electron beam processing, in a "cold" cross-linking process (below the crystal melting point). It provides less uniform, lower-degree cross-linking than the Engel method, especially at tube diameters over one inch (2.5 cm). When the process is not controlled properly, the outer layer of the tube may become brittle. However, it is the cleanest, most environmentally friendly method of the three, since it does not involve other chemicals and uses only high-energy electrons to split the carbon-hydrogen bonds and facilitate cross-linking.

25.4 Plumbing

PEX tubing is widely used to replace copper in plumbing applications. One estimate is that residential use of PEX for delivering drinking water to home faucets has increased by 40% annually,[2] and there is substantial evidence that PEX is or will soon become the dominant technology for carrying water in homes and businesses in the next decade or so. It is widely accepted among different groups, and has been used by volunteer organizations such as Habitat for Humanity in constructing homes. In 2006, *The Philadelphia Inquirer* recommended that plumbing installers switch from copper pipes to PEX.[3]

In the 20th century, mass-produced plumbing pipes were made from galvanized steel. As users experienced problems with the internal build-up of rust, which reduced water volume, these were replaced by copper tubing in the late 1960s.[4] Plastic pipes with fittings using glue were used as well in later decades. Initially PEX tubing was the most popular way to transport water in hydronic radiant heating systems, and it was used first in hydronic systems from the 1960s onwards.[2] Hydronic systems circulate water from a boiler or heater to places in the house needing heat, such as baseboard heaters or radiators.[5] PEX is suitable for recirculating hot water.[6]

Gradually PEX became more accepted for more indoor plumbing uses, such as carrying pressurized water to fixtures throughout the house. Increasingly, in the 2000s, copper pipes as well as plastic PVC pipes are being replaced with PEX.[4] PEX can be used for underground purposes, although one report suggested that appropriate "sleeves" be used for such applications.[6]

25.4.1 Benefits

Benefits of using PEX in plumbing include:

- **Flexibility**. PEX has become a contender for use in residential water plumbing because of its flexibility.[7] It can bend into a wide-radius turn if space permits, or accommodate turns by using elbow joints. In addition, it can handle short-radius turns, sometimes supported with a metal brace; in contrast, PVC, CPVC and copper all require elbow joints. A single length of PEX pipe cannot handle a sharp 90-degree turn, however, so in those situations, it is necessary to connect two PEX pipes with a 90-degree PEX elbow joint.

- **Direct routing of pipes**. PEX can run straight from a distribution point to an outlet fixture without cutting or splicing the pipe. This reduces the need for potentially weak and costly joints and reduces the drop in pressure due to turbulence induced at transitions. Since PEX is flexible, it is often possible to install a supply line directly from the water source to an appliance using just one connection at each end.[2]

- **Greater water pressure at fixtures.** Since PEX pipes typically have fewer sharp turns, there is greater water pressure at the sinks and showers and toilets where it is needed.

- **Lower materials cost**. Cost of materials is approximately 25% of alternatives.[8][9] One account suggested that the price of copper had quadrupled from 2002 to 2006.[2]

- **Easier installation**. Installing PEX is much less labor-intensive than copper pipes, since there is no need to use torches to solder pipes together, or to use glue to attach pipes to fittings.[8] One home inspector wrote that "Once you've worked with PEX, you'll never go back to that other stinky glue stuff."[10] Builders putting in radiant heating systems found that PEX pipes "made installation easy and operation problem-free".[7] PEX connections can be made by pushing together two matching parts using a compression fitting, or by using an adjustable wrench or a special crimping tool.[2] Generally, fewer connections and fittings are needed in a PEX installation.[3]

- **Reliable**. It neither corrodes nor develops so-called "pinhole" leaks.[3]

- **No fire risk during installation**. The oldest and most common method for joining copper piping is to solder pieces together using a torch. With an open flame there is always the risk of causing a fire in the surrounding structure, but PEX installation does not require a flame. However, there was an unfortunate counter-incident in 2011 in which authorities suspect that six firefighters were injured in a ceiling collapse. A fire melted PEX pipes, causing water to soak into ceiling insulation, adding weight which caused the ceiling to collapse. The PEX tubing was not blamed as the cause of the fire.[11] Overall PEX piping is much safer to install.

- **Acceptance by plumbers**. There are routinely advertisements for plumbers specifically seeking ones with PEX experience.

- **Ability to merge new PEX with existing copper and PVC systems**. Manufacturers make fittings allowing installers to join a copper pipe on one end with a PEX line at the other,[2] as well as giving options to reduce or expand the diameter of the pipes.

- **Longevity**. The advantageous properties of PEX also make it a candidate for progressive replacement of metal and thermoplastic pipes, especially in long-life applications, because the expected lifetime of PEX pipes reaches 50 years. However, the longest warranty offered by any PEX producer is 25 years.

- **Suitable for hot and cold pipes**. A convenient arrangement is to use color-coding to lessen the possibility of confusion.[10] Typically, red PEX tubing is used for hot water while blue PEX tubing is used for cold water.[3]

- **Less likely to burst from freezing**. The general position is that PEX plastic materials are slower to burst than copper or PVC pipes, but that they will burst eventually since freezing causes water to expand.[12] One account suggested that PEX water-filled pipes, frozen over time, will swell and tear; in contrast, copper pipe "rips" and PVC "shatters".[13] Home expert Steve Maxwell suggested in 2007 that PEX water-filled pipes could endure "five or six freeze-thaw cycles without splitting" while copper would split apart promptly on the first freeze.[14] In new unheated seasonal homes, it is still recommended to drain pipes during an unheated cold season or take other measures to prevent pipes from bursting because of the cold. In new construction, it is recommended that all water pipes be sloped slightly to permit drainage, if necessary.[14]

- **No corrosion**. Copper and iron pipes can experience corrosion leaks but PEX does not have these problems.

- **Environmental benefits**. One account suggested that PEX used in radiant heating was better for the environment than copper, although it noted that the pipes were based on petroleum products.[9]

- **Pipe insulation possible**. Conventional foam wrap insulation materials can be added to PEX piping to keep hot water hot, and cold water cold, and prevent freezing, if necessary.[15]

25.4.2 Drawbacks

- **Degradation from sunlight.** PEX tubing cannot be used in applications exposed to sunlight, as it degrades fairly rapidly.[16] Prior to installation it must be stored away from sunlight, and needs to be shielded from daylight after installation. Leaving it exposed to direct sunlight for as little as 30 days may result in premature failure of the tubing due to embrittlement.[16]

- **Perforation by insects.** PEX tubing is vulnerable to being perforated by the mouthparts of plant-feeding insects; in particular, the Western conifer seed bug (*Leptoglossus occidentalis*) is known to sometimes pierce through PEX tubing, resulting in leakage.[17]

- **Problems with yellow brass fittings**. There have been some claimed PEX systems failures in the U.S., Canada and Europe resulting in several pending class action lawsuits. The failures are claimed to be a result of the brass fittings used in the PEX system. Generally, builders and manufacturers have learned from these experiences and have found the best materials for use in fittings used to connect pipe with connectors, valves and other fittings. But there were problems reported with a specific type of brass fitting used in connection with installations in Nevada that caused a negative interaction between its mineral-rich hard water[18] and so-called "yellow brass" fittings.[6] Zinc in the fittings leached into the pipe material in a chemical reaction known as dezincification, causing some leaks or blockages.[18] A solution was to replace the yellow brass fittings, which had 30% zinc, with red brass fittings, which had 5% to 10% zinc.[18] It led California building authorities to insist on fittings made from "red brass" which typically has a lower zinc content, and is unlikely to cause problems in the future since problems with these specific fittings have become known.[6]

- **Initial adjustment to a new plumbing system**. There were a few reported problems in the early stages as plumbers and homeowners learned to adjust to the new fittings, and when connections were poorly or improperly made, but home inspectors have generally not noticed any problems with PEX since 2000.[19]

- **Can't use adhesives for pipe insulation**. One source suggested that pipe insulation, applied to PEX using certain adhesives, could have a detrimental effect causing the pipe to age prematurely; however, other insulating materials can be used, such as conventional foam wrap insulation, without negative effects.[15]

- **Fittings somewhat more expensive**. Generally, PEX fittings, particularly the do-it-yourself compression ones, are more expensive than copper ones, although there is no soldering required.[2] Due to the flexibility of PEX, it generally requires fewer fittings, which tends to offset the higher cost per fitting.

- **Potential problems for PEX radiant heating with iron-based components**. If plain PEX tubing is used in a radiant heating system that has ferrous radiators or other parts, meaning they are made out of iron or its alloys, then there is the possibility of rust developing over time; if this is the case, then one solution is to have an "oxygen barrier" in these systems to prevent rust from developing. Most modern installations of PEX for heating use oxygen barrier coated PEX.

- **Possible health effects.** There was controversy in California during the 2000s about health concerns. Several groups blocked adoption of PEX for concerns about chemicals getting into the water, either from chemicals outside the pipes, or from chemicals inside the pipes such as methyl tertiary butyl ether and tertiary butyl alcohol.[20] These concerns delayed statewide adoption of PEX for almost a decade. After substantial "back-and-forth legal wrangling", which was described as a "judicial rollercoaster", the disputing groups came to a consensus, and California permitted use of PEX in all occupancies.[21][22] An environmental impact report and subsequent studies determined there were no causes for concerns about public health from use of PEX piping.[21]

25.4.3 Government approvals

PEX has been approved for use in all fifty states of the United States as well as Canada,[3] including the initially reluctant state of California, which approved its use in 2009.[6] California allowed the use of PEX for domestic water systems on a case-by-case basis only in 2007.[23] This was mostly due to issues with corrosion of the manifolds, not the tubing itself, and was allowed in California when used in hydronic radiant heating systems. In 2009, the Building Standards Commission approved PEX plastic pipe and tubing to the California Plumbing Code (CPC), allowing its use in hospitals, clinics, residential and commercial construction throughout the state.[6] Formal adoption of PEX into the CPC occurred on August 1, 2009, allowing local jurisdictions to approve its general use,[24] although there were additional issues, and new approvals were issued in 2010 with revised wordings of the 2007 act.[25]

25.4.4 Competitors to PEX

Alternative plumbing choices include:

- **Aluminum plastic composite** are aluminum tubes laminated on the interior and exterior with plastic layers for protection.[3]

- **Corrugated stainless steel tubing**, continuous flexible pipes made out of stainless steel with a PVC exterior and are air-tested for leaks.[3]

- **Polypropylene Pipe**, similar in application to CPVC but a chemically inert material containing no harmful substances and reduced dangerous emissions when consumed by fire. It is primarily utilized in radiant floor systems but is gaining popularity as a leach-free domestic potable water pipe, primarily in commercial applications.
- **Polybutylene (PB) Pipe** is a form of plastic polymer that was used in the manufacture of potable water piping from late 70's until 1995. However, it has been discovered that as polymer pipe ages and reacts with chlorine (a common chemical used to purify water), it begins to degrade and can leak, causing damage to the surrounding building structure. Due to the inherent weakness of Polybutylene, the pipe is not accepted in Canada and U.S.

25.4.5 PEX-AL-PEX

PEX-AL-PEX pipes, or **AluPEX**, or **PEX/Aluminum/PEX**, or **Multilayer** pipes are made of a layer of aluminum sandwiched between two layers of PEX. The metal layer serves as an oxygen barrier, stopping the oxygen diffusion through the polymer matrix, so it cannot dissolve into the water in the tube and corrode the metal components of the system.[26] The aluminium layer is thin, typically 1 or 2 mm, and provides some rigidity to the tube such that when bent it retains the shape formed (normal PEX tube will spring back to straight). The aluminium layer also provides additional structural rigidity such that the tube will be suitable for higher safe operating temperatures and pressures.

25.4.6 PEX tool kit

A PEX tool kit includes a number of basic tools required for making fittings and connections with PEX tubing. In most cases, such kits are either bought at a local hardware store, plumbing supply store or assembled by either a home owner or a contractor. PEX tools kits range from under $100 and can go up to $300+. A typical PEX tool kit includes crimp tools, an expander tool for joining, clamp tools, PEX cutters, rings, boards, and staplers.

25.5 Other uses for PEX

- **Artificial joints**. Highly cross-linked polyethylene is used in artificial joints as a wear-resistant material. Cross-linked polyethylene is preferred in hip replacement because of its resistance to abrasive wear. Knee replacement, however, requires PE made with different parameters because cross-linking may affect mechanical strength and there is greater stress-concentration in knee joints due to lower geometric congruency of the bearing surfaces. Manufacturers start with ultra high molecular weight polyethylene, and crosslink with either electron beam or gamma irradiation.
- **Dental applications**. Some application of PEX has also been seen in dental restoration as a composite filling material.
- **Watercraft**. PEX is also used in many canoes and kayaks. The PEX is listed by the name Ram-X, and other brand specific names. Because of the properties of Cross-Linked Polyethylene, repair of any damage to the hull is rather difficult. Some adhesives, such as 3M's DP-8005, are able to bond to PEX, while larger repairs require melting and mixing more Polyethylene into the canoe/kayak to form a solid bond and fill the damaged area.
- **Power cable insulation**. Cross-linked polyethylene is widely used as electrical insulation in power cables of all voltage ranges but it is especially well suited to medium voltage applications. It is the most common polymeric insulation material. The acronym XLPE is commonly used to denote cross-linked polyethylene insulation.
- **Automotive Ducts & Housings**. PEX also referred to as XLPE is widely used in the aftermarket automotive industry for cold air intake systems and filter housings. Its properties include high heat deflection temperature, good impact resistance, chemical resistance, low flexural modulus and good environmental stress crack resistance. This form of XLPE is most commonly used in rotational molding; the XLPE resin comes in the form of a 35 mesh (500 µm) resin powder.

25.6 See also

- Low-density polyethylene (LDPE)
- Linear low-density polyethylene (LLDPE)
- High-density polyethylene (HDPE)
- Medium-density polyethylene (MDPE)
- Ultra-high-molecular-weight polyethylene (UHMWPE)
- Stretch wrap

25.7 References

[1] Rafferty KD (2007). "Piping". *Geo-Heat Center Quarterly Bulletin* **19** (1). Archived from Scholar search the original on March 6, 2008. Retrieved 2008-06-12.

[2] Jay Romano (September 3, 2006). "If Copper Pipes Are Too Costly ...". *The New York Times*. Retrieved 2011-07-09. The price of copper has nearly quadrupled over the last four years, and plumbers and do-it-yourselfers are taking a fresh look at alternatives to copper tubing and fittings. And what some are turning to is a flexible synthetic material called PEX.

[3] Alan J. Heavens (July 29, 2006). "Shortages Persist In Building Materials: Even as Demand for New Homes Falls, Cost of Cement and Copper Skyrockets`". *The Philadelphia Inquirer*. p. F25. Retrieved 2011-07-09. Recommended alternatives to copper piping include: (1) Cross-linked polyethylene, which is known as PEX and has been adopted by installers of radiant-floor heating since it neither corrodes nor develops pinhole leaks. PEX also resists chlorine and scaling, and uses fewer fittings than rigid plastic and metallic pipe. The piping is approved for potable hot- and cold-water plumbing systems as well as for hydronic heating systems in all plumbing and mechanical codes in the United States and Canada. (2) Aluminum plastic composite, a multipurpose pressure piping that can distribute hot and cold water indoors and outdoors, and also is well-suited for under-the-floor heating and snowmelt systems. It is made of aluminum tube laminated to interior and exterior layers of plastic. (3) Corrugated stainless-steel tubing, which is used as an alternative to traditional threaded black-iron gas piping for residential, commercial and industrial applications. It consists of a continuous, flexible stainless-steel pipe with an exterior PVC covering. The piping is produced in coils that are air-tested for leaks.

[4] Barry Stone (July 22, 2006). "50-Year-Old House Warrants Special Scrutiny". *The Washington Post*. Retrieved 2011-07-09. The use of galvanized steel water piping was abandoned in favor of copper in the late 1960s, and now the plumbing industry has moved from copper to PEX (cross-link polyethylene). The problem with old galvanized pipes is that they usually have internal rust build-up, which reduces water volume.... (Barry Stone => home inspector)

[5] Al Heavens (January 20, 2011). "Trying to keep radiant floor project out of hot water". *Chicago Tribune*. McClatchy/Tribune News. Retrieved 2011-07-09. Hydronic systems circulate water from a boiler or water heater through loops of polyethylene tubing, often called by the brand name Pex, but there are others. Tubing is typically installed on top of the subfloor in grooved panels or snap-in grids; clipped into aluminum strips on the underside of the floor; or embedded in poured concrete, or a lighter, concrete-like material in bathrooms or kitchens especially.

[6] Robert P. Mader (Sep 2, 2010). "California approves PEX for plumbing — again". Contractor Mag. Retrieved 2011-07-09. PEX became part of the California Plumbing Code in August 2009, following the CBSC's January 2009 certification of an Environmental Impact Report (EIR) on PEX and the commission's ensuing unanimous adoption of regulations approving PEX water distribution systems.... The Commission's action allows the statewide use of PEX in hospitals, clinics, schools, residences and commercial structures.... The CBSC reinstated PEX with the caveats that underground PEX must be sleeved, the material had to stand up to recirculating hot water, the fittings won't de-zincify, and PEX systems had to be filled and flushed....

[7] Alan J. Heavens (August 11, 2006). "No cool solution to removing heated tiles". *The Philadelphia Inquirer*. Retrieved 2011-07-09. I assume that the radiant floor heating involves piping that is embedded in Gypcrete, a lightweight blend of concrete and gypsum that, in concert with a shift to flexible PEX piping, has made installation easy and operation problem-free.

[8] Television program *Ed The Plumber*, DIY Network, 2006

[9] Jan Ellen Spiegel (April 20, 2008). "The House That Green Built". *The New York Times*. Retrieved 2011-07-09. (Page 2 of 4) There is radiant floor heating, and the toilets use rainwater stored in a cistern. The floors, doors and wall paneling are reclaimed from vintage homes that were torn down elsewhere in the state. Instead of copper pipes, water will travel through Pex piping, less expensive flexible polyethylene tubes that are petroleum-based, but still may be greener than copper pipe. "It is a compromise," said Mr. Johnson, who said he worried a little about the health aspects of Pex. "I couldn't get a good read on that, to tell you the truth. I sort of got exhausted in asking a bunch of people."

[10] John Kogel (2009-07-13). "Pex issues". *Inspection News*. Retrieved 2011-07-09. Once you've worked with PEX, you'll never go back to that other stinky glue stuff. We see copper stubs at the water heater (sometimes), the rest is PEX. Also, when they use the red and blue colors, hot is hot and cold is cold

[11] Michael Finnegan (February 21, 2011). "Officials probe structural issues in home where L.A. firefighter killed". Los Angeles Times. Retrieved 2011-07-09. Running through the attic were plastic pipes for fire sprinklers. The fire melted the pipes, flooding the attic and filling the insulation with water, Peaks said. The weight of the insulation appears to have caused a large section of the ceiling to collapse, injuring Allen and five other firefighters, officials said.

[12] Jay Romano (January 28, 2009). "Before, and After, the Last Drop". *The New York Times*. Retrieved 2011-07-09. Pipes, traditionally made of copper, can burst if the water inside freezes, because water expands when frozen, but copper does not. If the water expands too much, it has nowhere to go but out, forcing the pipe to burst at the frozen spot. Tom Kraeutler, a host of the syndicated radio show "The Money Pit", said most houses have one particular spot where the pipes tend to freeze. If there is fairly consistent freezing in an area, he said, it is wise to reroute the pipes and to replace them with PEX — a flexible plastic tubing that is much less likely to burst than copper. Like copper, though, PEX can freeze, as Mr. Carter, who

moved in December, now knows. The house was built with modern materials, including PEX, but because the place was only six years old, he didn't think he had to worry about frozen pipes.

[13] Stacy Downs (February 24, 2006). "Frozen pipes can lead to flood of woe". *Chicago Tribune*. Knight Ridder/Tribune. Retrieved 2011-07-09. Frozen pipes break differently depending on the material, Water said. Copper rips, PVC (polyvinyl chloride) shatters and PEX (polyethylene) swells and tears.

[14] Steve Maxwell (Jul 14, 2007). "Drywall may not work on waterfront". *Toronto Star*. Retrieved 2011-07-09. Start by making sure that all runs of water supply pipe are sloped downwards slightly to central drain valves. Also, be sure to specify that all drain traps remain accessible, and be the kind that includes a removable plug on the bottom. As an added precaution, install PEX-al-PEX supply pipes instead of copper. If water accidentally remains in these pipes, they'll endure five or six freeze-thaw cycles without splitting. Copper pipe, on the other hand, splits apart promptly when it contains water that freezes.

[15] Steve Maxwell (Feb 28, 2009). "Put basement repair to wet weather test". *Toronto Star*. Retrieved 2011-07-09. Q: Is it safe to use pipe wrap insulation on PEX water supply pipes? In a magazine put out by a home improvement retailer, it warns that a chemical reaction between insulation and PEX will eventually destroy the pipes. Is this true? A: To answer your question, I contacted one of the world's largest producers of PEX pipe. The only potential issue they know of has to do with certain types of adhesives touching the pipe surface. PEX includes antioxidants for stabilizing against chlorine, and these antioxidants can become destabilized in a reaction with adhesives, possibly aging the pipe prematurely. That said, they don't know of any issues relating to a chemical reaction between PEX and conventional foam pipe wrap insulation. I've installed foam insulation on PEX in my own house about a year ago, and there's no visible signs of trouble.

[16] Bill Kibbel (Historic & Commercial Building Inspections), Jim Katen, Nolan E. Kienitz (home inspectors) (2006–2007). "PEX and sunlight issues". The Inspector's Journal. Retrieved 2011-07-09. Well, the manufacturers' instruction I've read and the Plastic Pipe Assoc. says it can't be installed where exposed to direct sunlight.... I've heard of some pretty serious problems with PEX that's exposed to sunlight. Your client's concerns are valid.... Another big factor is how the product has been "handled" from manufacture to site installation.... I had a client, with a new home, that was purchased back by the plumbing company due to mis-handling of the PEX that had caused over 10 leaks in less than 7 months.

[17] Bates, S.L. 2005. Damage to common plumbing materials caused by overwintering *Leptoglossus occidentalis* (Hemiptera: Coreidae). Canadian Entomologist 137: 492-496.[journals.cambridge.org/article_S0008347X00002807]

[18] Jeff Pope (Jan 22, 2009). "Pipe work begins in homes involved in Kitec lawsuit". *Las Vegas Sun*. Retrieved 2011-07-09. The polyethylene pipes contained a thin layer of aluminum that held its shape as plumbers twisted and bent it. Plastic pipes without the aluminum require more anchoring because they spring back to a straight line. The pipes aren't failing though. It's the brass fittings that connect the pipes to copper fixtures on valves, water heaters and softeners. The problem is a chemical reaction known as dezincification, which accelerates corrosion in brass fittings when they are exposed to oxygen and moisture. Brass is an alloy primarily composed of copper and zinc. When dezincification occurs, zinc leaches out of the fittings, leaving a blockage of zinc oxide that leads to leaks, restricted water flow and breaks.

[19] Ted Menelly (2009-07-13). "Pex issues". Inspection News. Retrieved 2011-07-09. Just a couple of leaks at poorly applied connections. Other than that I have not really seen any. Most, not all, but most new homes have PEX. There are some that still use only copper. have seen it used a lot in remodel with many homes I have inspected that have had repiping. It is easier to run through the attics and crawls. I guess it has been, what, 10 years or so since its major use. I guess only time will tell. There were many complaints in the very beginning but not much now.

[20] "California Building Standards Code" (PDF). State of California. 2007. Retrieved 2011-08-15. ... PEX material is susceptible to chemical leaching, both from the outside environment and chemicals leaching out of the PEX material itself....

[21] "Pipe Rollercoaster: After a recent exclusion, PEX pipe is back in the California Plumbing Code". *Plumbing & Mechanical*. October 1, 2010. Retrieved 2011-08-15. ... controversy in California ... resulting in a flurry of back-and-forth legal wrangling over health, safety and performance issues related to the flexible pipe.... That judicial rollercoaster finally came to a halt in mid-August when a coalition of consumer, environmental, public health and labor organizations reached an agreement with the state and the plastic pipe industry ... As a result, the California Building Standards Commission now allows the use of PEX in all occupancies...

[22] Jack Sweet (October 1, 2010). "What was that flurry of activity this past summer?". Reeves Journal. Retrieved 2011-08-15. It boiled up, came to a head and was then over almost as quickly as it takes to tell the tale. PEX, formally known as crosslinked polyethylene tubing-was given the administrative heave-ho from the California plumbing codes. Then, almost as quickly as the word could get passed out to the industry-at-large, PEX was back the state's good graces, albeit with a few stipulations on its use that weren't there before.

[23] 2007 CPC Table 6-4 Footnote 1; previously: 2001 CPC 604.1 #2

[24] "(Press Release) PEX Plastic Pipe Unanimously Added to California Plumbing Code; State Officials Certify Favorable Environmental Impact Report". *Reuters*. January 27, 2009. Retrieved June 23, 2009.

[25] "Building Standards Commission". State of California. 2010. Retrieved 2011-07-09. On August 16, 2010, the California Building Standards Commission certified the

Final Environmental Impact Report and approved regulations allowing the use of PEX tubing. The Approved Final Express Terms document represents the final language that will be published into the 2007 California Plumbing Code and the 2010 California Plumbing Code (Effective Jan. 1, 2011) with the strikeout and underlining removed for clarity. All remaining agencies' rulemaking documents appearing on this page, were also approved by the Commission, but do not have the strikeout and underlined removed.

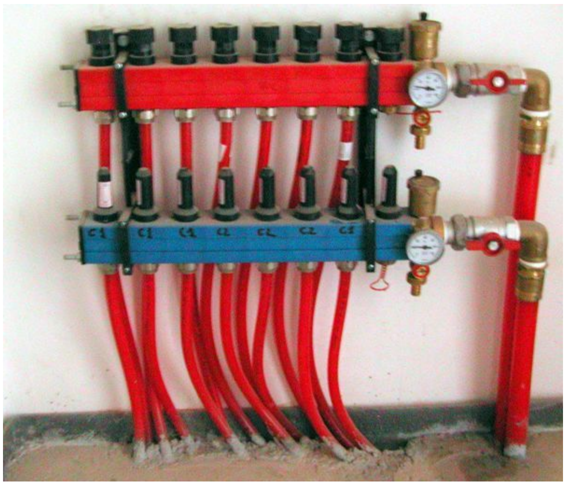
[26] "PEX choices". *Home Heating Systems Newsletter*. Archived from the original on June 11, 2008. Retrieved 2008-06-12.

25.8 External links

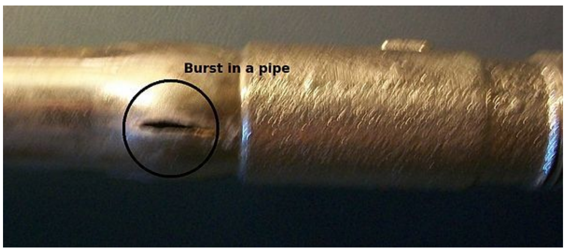
- Why is Polybutylene pipe such big deal? Alternative view on PB piping.
- History of PEX on Plastic Pipe and Fittings Association (PPFA) homepage
- PEX FAQs on Plastic Pipe and Fittings Association (PPFA) homepage
- As a viable Polybutulene repipe option.
- Analytical techniques to characterize crosslinked polyethylene

A cross-linked polyethylene (PEX) pipe

Raw material: XLPE powder used in Rotational molding in a factory.



Radiant heating system manifold using PEX tubing.

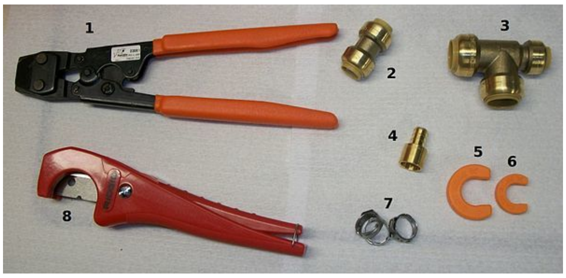


All pipes, including this copper exterior valve as well as PEX, can burst from freezing, although several reports suggest that PEX takes longer to burst under freezing conditions.

PEX's flexibility means fewer connections, better water flow, faster and easier installations.

A PEX compression fitting makes it possible to join copper and PEX pipes by simply pushing them together for a watertight fit.

Brass Crimp fittings - Other popular type of fittings primarily used for connection PEX to PEX, PEX to Threaded pipes. 1.Drop Ear Elbows connect PEX and threaded pipe at a 90-degree 2.PEX to Copper Adapter 3.PEX to Solder Threaded Adapter 4.PEX Plug - terminate end of pipe 5.PEX to Female Threaded Adapter 6.PEX to PEX Coupling 7.PEX to PEX 90-degree Elbow 8.PEX to Copper Adapter 9.PEX to Copper 90-degree Elbow 10. PEX x PEX x PEX 3-way PEX Tee.



Tools and fittings used in a plumbing installation with PEX piping. (1) crimping tool to squeeze a metal band to join a pipe and a fitting (2) compression coupling joining two 1/2 inch pipes (copper or PEX) (3) “T-joint” to connect 3/4”, 3/4”, and 1/2” pipes (4) Copper-to-PEX 1/2” connection (requires soldering) (5 and 6) tools to undo PEX connections (7) crimp rings to squeeze metal band to connect PEX to a fixture (8) PEX tube cutter.

XLPE automotive duct

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- **Multicore cable** *Source:* http://en.wikipedia.org/wiki/Multicore%20cable?oldid=617932074 *Contributors:* Danhash, Malcolma, Allens, C.Löser, SmilingFace, Alaibot, VoABot II, Squids and Chips, Kevinkor2, Tomas e, No such user, Joostik, Lam Kin Keung, EmausBot, K6ka, Wagino 20100516, NTox, JordoCo, Krishna1024 and Anonymous: 11
- **Ribbon cable** *Source:* http://en.wikipedia.org/wiki/Ribbon%20cable?oldid=648919722 *Contributors:* Heron, Booyabazooka, DopefishJustin, Mahjongg, Karada, Egil, Andrewa, Samw, Saltine, Wernher, Robbot, Donreed, Pascal666, Lovelac7, ArnoldReinhold, Plugwash, Aaronbrick, Kjkolb, Hooperbloob, Mac Davis, Wtshymanski, LOL, Nick1nildram, Ground Zero, Rockingbeat, Jidan, Turidoth, YurikBot, Hairy Dude, Retodon8, SmackBot, Doktor~enwiki, Kmarinas86, PetesGuide, A5b, Robofish, OnBeyondZebrax, Infodrenched, CmdrObot, Neelix, Synergy, James086, SNx, Mbushroe, Antur, 0612, HuntClubJoe, R'n'B, Signalhead, Andy Dingley, Brenont, CultureDrone, Loren.wilton, Itsnotmyfault1, Domni, Waterjack, Stickee, RobbertS, Addbot, UlfSamuelsson, Tothwolf, Not so old lion, Yobot, Ptbotgourou, AnomieBOT, Jsan92, A.amitkumar, Lotje, DARTH SIDIOUS 2, Caspertheghost, Hinata, Pantergraph, ChrisGualtieri, EvergreenFir, GravRidr, WPGA2345, Hoculi1960, Michaeljsantora1382 and Anonymous: 44
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- **Leaky feeder** *Source:* http://en.wikipedia.org/wiki/Leaky%20feeder?oldid=652663745 *Contributors:* The Anome, Freestylefrappe, Kjkolb, Thryduulf, Mpatel, NorsemanII, Back ache, Groyolo, SmackBot, Freewol, Chetvorno, N2e, No1lakersfan, Alaibot, Thijs!bot, X96lee15, Z22, Jim.henderson, Nikthestunned, AlleborgoBot, Onlyonefin, M.boli, XLinkBot, Addbot, Yobot, Povlhp, AnomieBOT, TiredAndConfused, Peterfreedom, Minesite, Erik9bot, Nicanor.errazuriz, Epicgenius and Anonymous: 15
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