Signal Cables in Telecommunications

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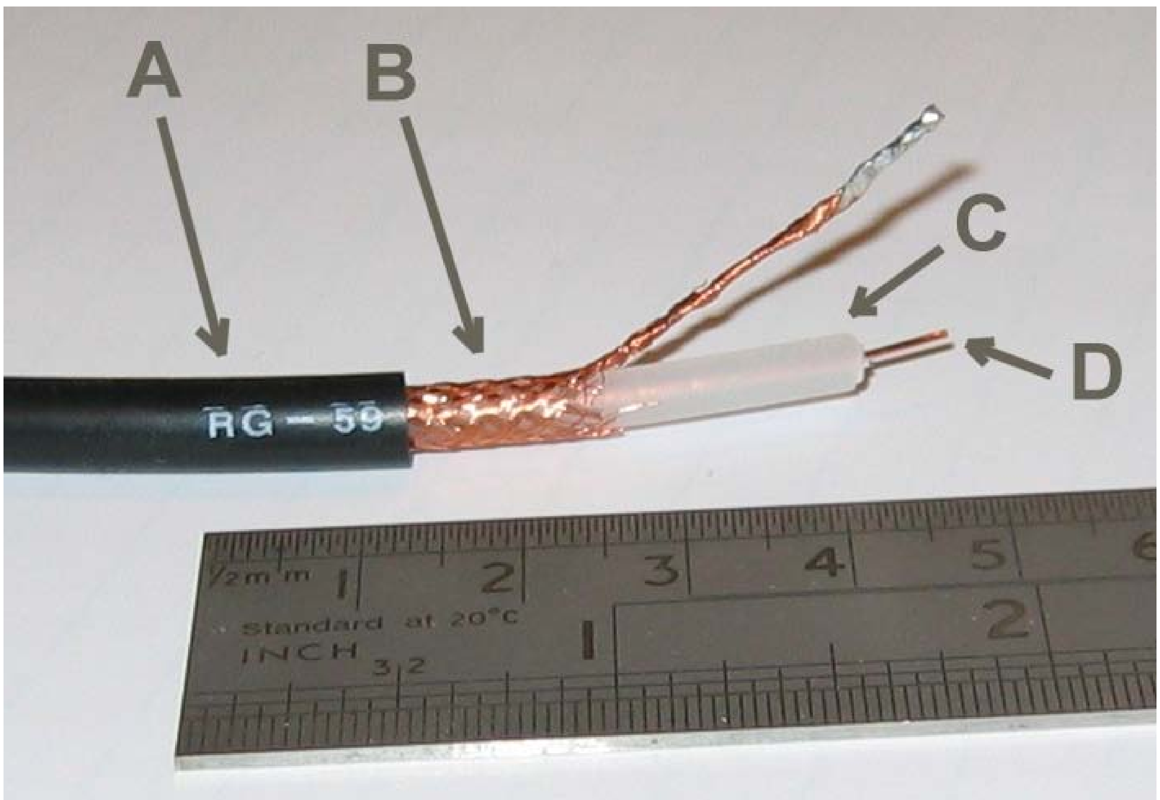
Coaxial Cable



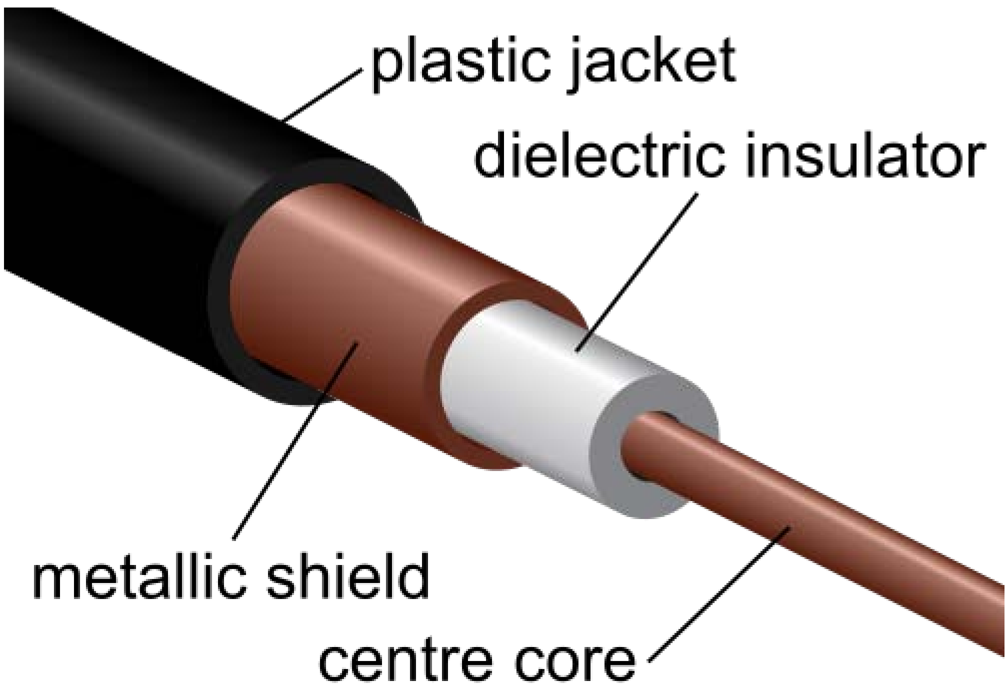
RG-59 **flexible coaxial cable** composed of:
A: outer plastic sheath
B: woven copper shield
C: inner dielectric insulator
D: copper core

Coaxial cable, or **coax**, is an electrical cable with an inner conductor surrounded by a flexible, tubular insulating layer, surrounded by a tubular conducting shield. The term coaxial comes from the inner conductor and the outer shield sharing the same geometric axis. Coaxial cable was invented by English engineer and mathematician Oliver Heaviside, who first patented the design in 1880.

Coaxial cable is used as a transmission line for radio frequency signals, in applications such as connecting radio transmitters and receivers with their antennas, computer network (Internet) connections, and distributing cable television signals. One advantage of coax 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, and provides protection of the signal from external electromagnetic interference.

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.

How it works



Coaxial cable cutaway

Like any electrical power cord, coaxial cable conducts AC electric current between locations. Like these other cables, it has two conductors, the central wire and the tubular shield. At any moment the current is traveling outward from the source in one of the conductors, and returning in the other. However, since it is alternating current, the current reverses direction many times a second. Coaxial cable differs from other cables because it is designed to carry radio frequency current. This has a frequency much higher than the 50 or 60 Hz used in mains (electric power) cables, reversing direction millions to billions of times per second. As with other types of radio transmission line, this requires special construction to prevent power losses.

If an ordinary wire is used to carry high frequency currents, the wire acts as an antenna, and the high frequency currents radiate off the wire as radio waves, causing power losses. To prevent this, in coaxial cable one of the conductors is formed into a tube and encloses the other conductor. This confines the radio waves from the central conductor to the space inside the tube. To prevent the outer conductor, or shield, from radiating, it is connected to electrical ground, keeping it at a constant potential.

The dimensions and spacing of the conductors must be uniform throughout the length of the cable. Any abrupt change in the spacing of the two conductors along the cable tends to reflect radio frequency power back toward the source, causing a condition called standing waves. This acts as a bottleneck, reducing the amount of power reaching the destination end of the cable. To hold the shield at a uniform distance from the central conductor, the space between the two is filled with a semirigid plastic dielectric. Manufacturers specify a minimum bend radius to prevent kinks that would cause reflections. The connectors used with coax are designed to hold the correct spacing through the body of the connector.

Each type of coaxial cable has a characteristic impedance depending on its dimensions and materials used, which is the ratio of the voltage to the current in the cable. In order to prevent reflections at the destination end of the cable from causing standing waves, any equipment the cable is attached to must present an impedance equal to the characteristic impedance (called 'matching'). Thus the equipment "appears" electrically similar to a continuation of the cable, preventing reflections. Common values of characteristic impedance for coaxial cable are 50 and 75 ohms.

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.

Description

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. Sometimes copper-plated iron wire is used as an inner conductor.

The insulator surrounding the inner conductor may be solid plastic, a foam plastic, or may be 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. 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 take sharp bends, 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 upwards. 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.

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.

Most cables have a solid dielectric; others have a foam dielectric which contains as much air as possible to reduce the losses. Foam coax will have about 15% less attenuation but can absorb moisture—especially at its many surfaces—in humid environments, increasing the loss. Stars or spokes are even better but more expensive. Still more expensive were the air spaced coaxials used for some inter-city communications in the middle 20th Century. The center conductor was suspended by polyethylene discs every few centimeters. In a miniature coaxial cable such as an 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. 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 to resist ultraviolet light and oxidation. For internal chassis connections the insulating jacket may be omitted.

The ends of coaxial cables are usually made with RF connectors.

Signal propagation

Open wire 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, twisted or otherwise shaped without changing their characteristic impedance, causing reflection of the signal back toward the source. They also cannot be 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 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) and/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.

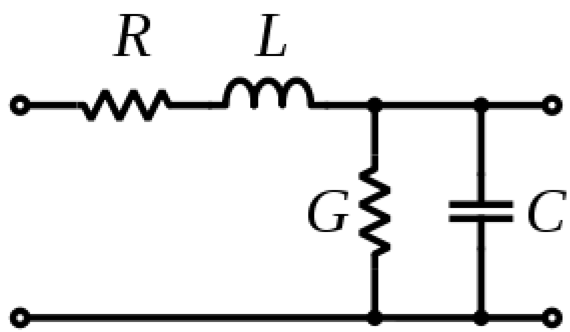
Connectors

A coaxial connector (male N-type).

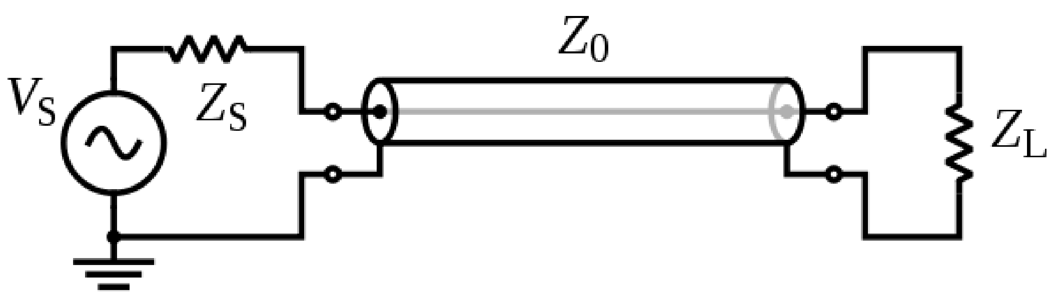
Coaxial connectors are designed to maintain a coaxial form across the connection and have the same well-defined impedance as the attached cable. Connectors are often plated with high-conductivity metals such as silver or gold. Due to the skin effect, the RF signal is only carried by the plating and does not penetrate to the connector body. Although silver oxidizes quickly, the silver oxide that is produced is still conductive. While this may pose a cosmetic issue, it does not degrade performance.

Important parameters

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



Schematic representation of the elementary components of a transmission line.



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

Physical parameters

In the following section, these symbols are used:

- 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: $\varepsilon = \varepsilon_r\varepsilon_0$. 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.

Fundamental electrical parameters

- Shunt capacitance per unit length, in farads per metre.

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

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

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

- 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.

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

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

  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).

- 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).

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

- Cutoff frequency is determined by the possibility of exciting other propagation modes in the coaxial cable. The average circumference of the insulator is $\pi(D + d) / 2$. Make that length equal to 1 wavelength in the dielectric. The TE01 cutoff frequency is therefore

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

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

$$V_p = 1150\ S_{mils}\ d_{in}\ \log_{10}(D/d)$$

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 as

$$V_p = 0.5\ S\ d\ \ln(D/d)$$

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.

Significance of impedance

The best coaxial cable impedances in high-power, high-voltage, and low-attenuation applications were experimentally determined in 1929 at Bell Laboratories to be 30, 60, and 77 Ω respectively. For an air dielectric coaxial cable with a diameter of 10 mm the attenuation is lowest at 77 ohms when calculated for 10 GHz. The curve showing the power handling maxima at 30 ohms can be found here:

CATV systems were one of the first applications for very large quantities of coaxial cable. CATV is typically using such low levels of RF power that power handling and high voltage breakdown characteristics were totally unimportant when compared to attenuation. Moreover, many CATV headends used 300 ohm folded dipole antennas to receive off the air TV signals. 75 ohm coax made a nice 4:1 balun transformer for these antennas as well as presented a nice attenuation specification. But this is a bit of a red herring: when normal dielectrics are added to the equation the best loss impedance drops down to values between 64 and 52 ohms. Details and a graph showing this effect can be found here: 30 Ω cable is more difficult to manufacture due to the much larger center conductor and the stiffness and weight it adds.

The arithmetic mean between 30 ohms and 77 ohms is 53.5; the geometric mean is 48 ohms. The selection of 50 ohms as a compromise between power handling capability and attenuation is generally cited as the reason for the number.

One reference to a paper presented by Bird Electronic Corp as to why 50 ohms was chosen can be found here:

50 Ohms works out well for other reasons, such as that it corresponds very closely to the drive impedance of a half wave dipole antenna in real environments, and provides an acceptable match to the drive impedance of quarter wave monopoles as well. 73 Ω is an exact match for a centre fed dipole aerial/antenna in free space (approximated by very high dipoles without ground reflections).

RG-62 is a 93 ohm coaxial cable, originally used in mainframe computer networks in the 1970s and early 1980s. It was the cable used to connect the terminals (IBM 3270) to the terminal cluster controllers (IBM 3274/3174). Later, some manufacturers of LAN equipment, such as Datapoint for ARCNET, adopted RG-62 as their coaxial cable standard. It 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 and is much more important than power handling or attenuation specifications in these environments.

All of the components of a coaxial system should have the same impedance to reduce internal reflections at connections between components. Such reflections increase signal loss and can result in the reflected signal reaching a receiver with a slight delay from the original. In analog video or TV systems this visual effect is commonly referred to as ghosting.

Issues

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.

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 copper shield would be heavy, inflexible, and expensive. Practical cables must make compromises between shield efficacy, flexibility and cost, such as the corrugated surface of hardline, flexible braid, or foil shields. Since the shields are not perfect conductors, electric fields can exist inside the shield, thus allowing radiating electromagnetic fields to go through 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 will 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.

This type of leakage can also occur at locations of poor contact between connectors at either end of the cable.

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.

Induction

External current sources like switched-mode power supplies create a voltage across the inductance 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 sometimes several times.

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, and would actually cause energy to radiate from the coax itself, making it appear to be part of the antenna, affecting the radiation pattern of the antenna and possibly introducing dangerous radio frequency energy into areas near people, with the risk of radiation burns if the coax is being used for sufficiently high power transmissions. A properly placed and sized balun can prevent common mode radiation in coax.

Miscellaneous

Some senders and receivers use only a limited range of frequencies and block all others by means of an isolating transformer. Such a transformer breaks the shield for high frequencies. Still others avoid the transformer effect altogether by using two capacitors. If the capacitor for the outer conductor is implemented as one thin gap in the shield, no leakage at high frequencies occurs. At high frequencies, beyond the limits of coaxial cables, it becomes more efficient to use other types of transmission line such as wave guides or optical fiber, which offer low leakage (and much lower losses) around 200 THz and good isolation for all other frequencies.

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.

Common Coaxial Cables

type	**impedance ohms**	**core**	**dielectric**				**overall diameter**		**shields**	**comments**	**max attenuation @ 750 MHz**
			type	**VF**	**in**	**mm**	**in**	**mm**			
RG-6/U	75	1.0 mm	PF	0.75	0.185	4.7	0.270	6.86	double	Low loss at high frequency for cable television, satellite television and cable modems	5.65dB/100 ft
RG-6/UQ	75		PF				0.298	7.57	quad	This is "quad shield RG-6". It has four layers of shielding; regular RG-6 only has one or two	5.65dB/100 ft
RG-7	75	1.30 mm	PF		0.225	5.72	0.320	8.13	double	Low loss at high frequency for cable television, satellite television and cable modems	4.57dB/100 ft
RG-8/U	50	2.17 mm	PE		0.285	7.2	0.405	10.3		Amateur radio; Thicknet (10BASE5) is similar	
RG-8X	50	1.0 mm	PF	0.75	0.185	4.7	0.242	6.1	double	A thinner version, with the electrical characteristics of RG-8U in a diameter similar to RG-6.	
RG-9/U	51		PE				0.420	10.7			
RG-11/U	75	1.63 mm	PE	0.66	0.285	7.2	0.412	10.5		Used for long drops and underground conduit	3.65dB/100 ft
RG-58/U	50	0.9 mm	PE	0.66	0.116	2.9	0.195	5.0	single	Used for radiocommunication and amateur radio, thin Ethernet (10BASE2) and NIM electronics. Common.	
RG-59/U	75	0.81 mm	PE	0.66	0.146	3.7	0.242	6.1	single	Used to carry baseband video in closed-circuit television, previously used for cable television. Generally it has poor shielding but will carry an HQ HD signal or video over short distances.	6.97dB/100 ft
3C-2V	75	0.50 mm	PE	0.85		3.0		5.4	single	Used to carry television, video observation systems, and other. PVC jacket.	
5C-2V	75	0.80 mm	PE	0.82 +/-2	0.181	4.6	0.256	6.5	double	Used for interior lines for monitoring system, CCTV feeder lines,	

										wiring between the camera and control unit and video signal transmission. PVC jacket.
RG-60/U	50	1.024 mm	PE				0.425	10.8	single	Used for high-definition cable TV and high-speed cable Internet.
RG-62/U	92		PF	0.84			0.242	6.1	single	Used for ARCNET and automotive radio antennas.
RG-62A	93		ASP				0.242	6.1	single	Used for NIM electronics
RG-174/U	50	0.48 mm	PE	0.66	0.100	2.5	0.100	2.55	single	Common for wifi pigtails: more flexible but higher loss than RG58; used with LEMO 00 connectors in NIM electronics.
RG-178/U	50	7×0.1 mm (Ag plated Cu clad Steel)	PTFE	0.69	0.033	0.84	0.071	1.8	single	Used for high frequency signal transmission.
RG-179/U	75	7×0.1 mm (Ag plated Cu)	PTFE	0.67	0.063	1.6	0.098	2.5	single	VGA RGBHV
RG-180B/U	95	0.0120 in (Ag plated Cu clad steel)	PTFE		0.102		0.145		single Ag covered Cu	VGA RGBHV
RG-213/U	50	7×0.0296 in Cu	PE	0.66	0.285	7.2	0.405	10.3	single	For radiocommunication and amateur radio, EMC test antenna cables. Typically lower loss than RG58. Common.
RG-214/U	50	7×0.0296 in	PE	0.66	0.285	7.2	0.425	10.8	double	Used for high frequency signal transmission.
RG-218	50	0.195 in Cu	PE	0.66	0.660 (0.680?)	16.76 (17.27?)	0.870	22	single	Large diameter, not very flexible, low loss (2.5dB/100' @ 400 MHz), 11kV dielectric withstand.
RG-223/U	50	0.88 mm	PE	0.66	0.0815	2.07	0.212	5.4	Double	Silver plated shields. Sample RG-223 Datasheet
RG-316/U	50	7x0.0067 in	PTFE	0.695	0.060	1.5	0.098	2.6	single	used with LEMO 00 connectors in NIM electronics;
H155	50			0.79						lower loss at high frequency for radiocommunication and amateur radio
H500	50			0.82						low loss at high frequency for radiocommunication and amateur radio
LMR-100	50							2.79		low loss communications, 1.36 dB/meter @ 2.4 GHz
LMR-195	50									low loss drop-in replacement for RG-58

LMR-200 HDF-200 CFD-200	50	1.12 mm Cu	PF CF	0.83	0.116	2.95	0.195	4.95		low loss communications, 0.554 dB/meter @ 2.4 GHz	
LMR-400 HDF-400 CFD-400	50	2.74 mm (Cu clad Al)	PF CF	0.85	0.285	7.24	0.405	10.29		low loss communications, 0.223 dB/meter @ 2.4 GHz	
LMR-600	50	4.47 mm (Cu clad Al)	PF	0.87	0.455	11.56	0.590	14.99		low loss communications, 0.144 dB/meter @ 2.4 GHz	
LMR-900	50	6.65 mm (BC tube)	PF	0.87	0.680	17.27	0.870	22.10		low loss communications, 0.098 dB/meter @ 2.4 GHz	
LMR-1200	50	8.86 mm (BC tube)	PF	0.88	0.920	23.37	1.200	30.48		low loss communications, 0.075 dB/meter @ 2.4 GHz	
LMR-1700	50	13.39 mm (BC tube)	PF	0.89	1.350	34.29	1.670	42.42		low loss communications, 0.056 dB/meter @ 2.4 GHz	
QR-320	75	1.80 mm	PF		0.395	10.03			single	Low loss line which replaced RG-11 in most applications	3.34dB/100 ft
QR-540	75	3.15 mm	PF		0.610	15.49			single	Low loss hard line	1.85dB/100 ft
QR-715	75	4.22 mm	PF		0.785	19.94			single	Low loss hard line	1.49dB/100 ft
QR-860	75	5.16 mm	PF		0.960	24.38			single	Low loss hard line	1.24dB/100 ft
QR-1125	75	6.68 mm	PF		1.225	31.12			single	Low loss hard line	1.01dB/100 ft

Dielectric Material Codes

- FPE is foamed polyethylene
- PE is solid polyethylene
- PF is polyethylene foam
- PF CF is polyethylene foam
- PTFE is polytetrafluoroethylene;
- ASP is air space polyethylene

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

- VF for solid PE is about 0.66
- VF for foam PE is about 0.79 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.

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.

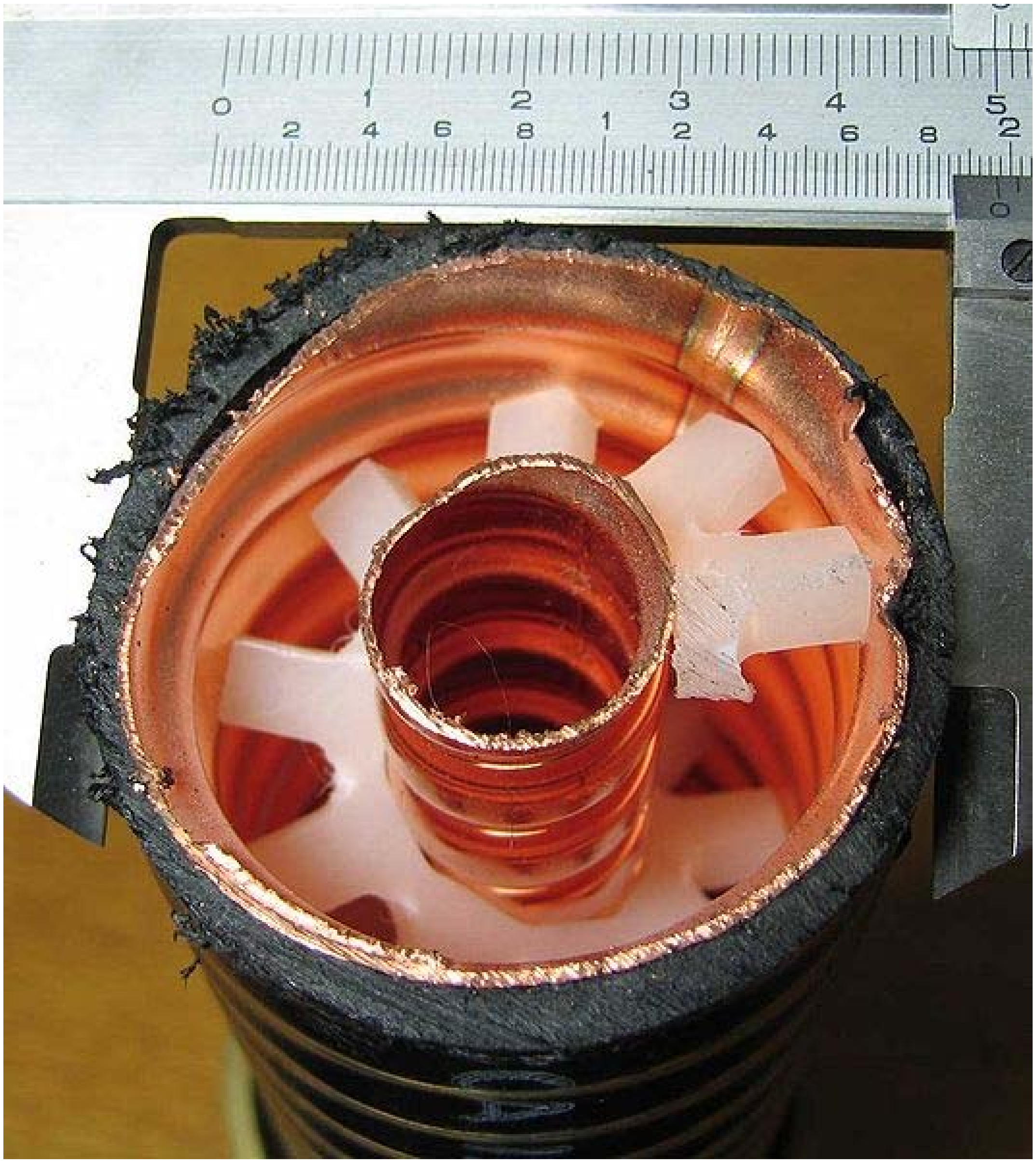
Long distance coaxial cable was used in the 20th century to connect radio networks, television networks, and Long Distance telephone networks though this has largely been superseded by later methods (fibre optics, T1/E1, satellite). Shorter coaxials still carry cable television signals to the majority of television receivers, and this purpose consumes the majority of coaxial cable production.

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.

Types

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), or Cablewave (RFS/Cablewave). Larger varieties of hardline may consist of a center conductor which 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, as well as a reduced risk of internal arcing. Gas-filled hardlines are usually used on high powered RF transmitters such as television or radio broadcasting, military transmitters, as well as high powered amateur radio applications but may also be used on some critical lower powered applications such as those in the microwave bands. Although 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, particularly in equipment within the microwave range, to reduce interference between stages of the device.

Radiating

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, underground, transportation tunnels and in other areas where an antenna is not feasible. One example of this type of cable is Radiax (Andrew).

RG-6

RG-6 is available in four different types designed for various applications. "Plain" or "house" wire is designed for indoor or external house wiring. "Flooded" cable is infused with heavy waterproofing for use in underground conduit (ideally) 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" wire comes with a special Teflon outer jacket designed for use in ventilation ducts to meet fire codes.

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.

Twin-axial cable

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.

Biaxial cable

Biaxial cable, **biax** or *Twin-Lead* is a figure-8 configuration of two 50 Ω coaxial cables, externally resembling that of lamp cord, or speaker wire. Biax is used in some proprietary computer networks. Others may be familiar with 75Ω biax which at one time was popular on many cable TV services.

Semi-rigid

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.

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 withouth the need for specialist tools, similar to standard coaxial cable.

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 absorbing 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.

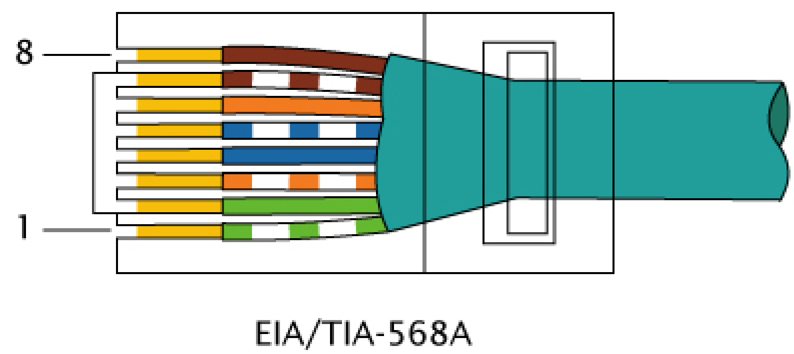
In the United States and some other countries, cable television distribution systems use extensive networks of outdoor coaxial cable, often with in-line distribution amplifiers. Leakage of signals into and out of cable TV systems can cause interference to cable subscribers and to over-the-air radio services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

History

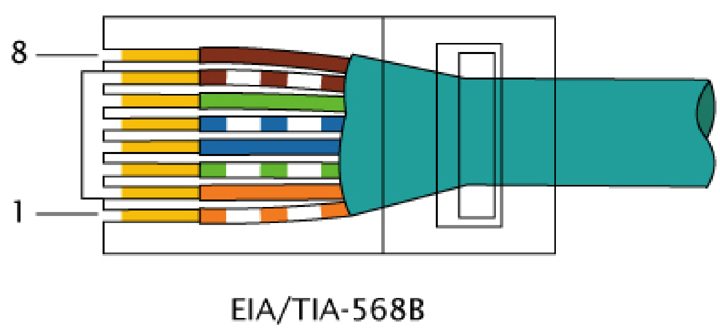
- 1866 — First successful transatlantic cable, designed by William Thomson (Lord Kelvin, 1892).
- 1880 — Coaxial cable patented in England by Oliver Heaviside, patent no. 1,407.
- 1884 — Siemens & Halske patent coaxial cable in Germany (Patent No. 28,978, 27 March 1884).
- 1894 — Oliver Lodge demonstrates waveguide transmission at the Royal Institution. Nikola Tesla receives U.S. Patent 0,514,167, *Electrical Conductor*, on February 6.
- 1929 — First modern coaxial cable patented by Lloyd Espenschied and Herman Affel of AT&T's Bell Telephone Laboratories.
- 1936 — First closed circuit transmission of TV pictures on coaxial cable, from the 1936 Summer Olympics in Berlin to Leipzig.
- 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.
- 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.
- 1936 — Coaxial cable laid by the General Post Office (now BT) between London and Birmingham, providing 40 telephone channels.
- 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.
- 1956 — First transatlantic coaxial cable laid, TAT-1.

Chapter-2

Ethernet Crossover Cable



T568A connector wiring



T568B connector wiring

An **Ethernet crossover cable** is a type of Ethernet cable used to connect computing devices together directly where they would normally be connected via a network switch, hub or router, such as directly connecting two personal computers via their network interface controllers.

Owing to the inclusion of automatic MDI/MDI-X configuration capability in most modern Ethernet equipment, use of crossover cables is typically only necessary in older network installations.

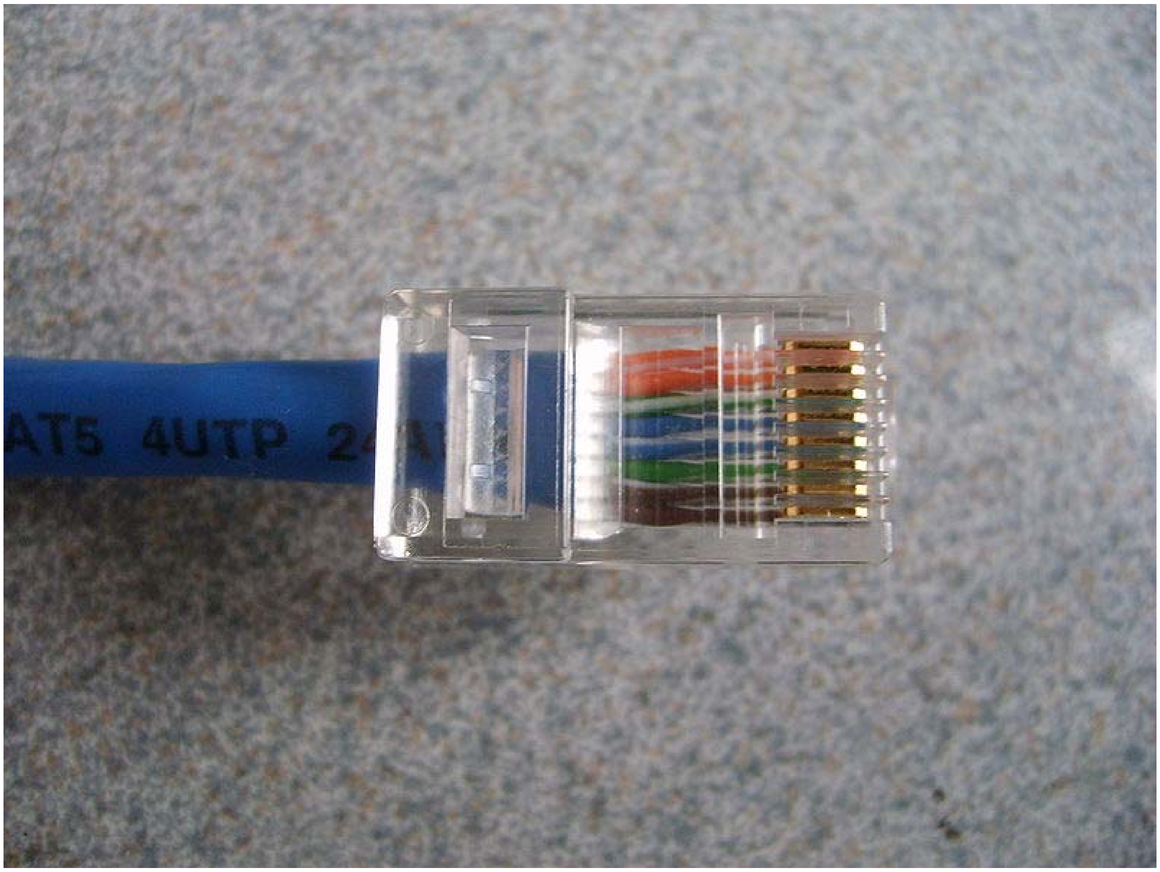
Overview

The 10BASE-T and 100BASE-TX Ethernet standards use one wire pair for transmission in each direction. The Tx+ line from each device connects to the tip conductor, and the Tx- line is connected to the ring. This requires that the transmit pair of each device be connected to the receive pair of the device on the other end. When a terminal device is connected to a switch or hub, this crossover is done internally in the switch or hub. A standard *straight through* cable is used for this purpose where each pin of the connector on one end is connected to the corresponding pin on the other connector.

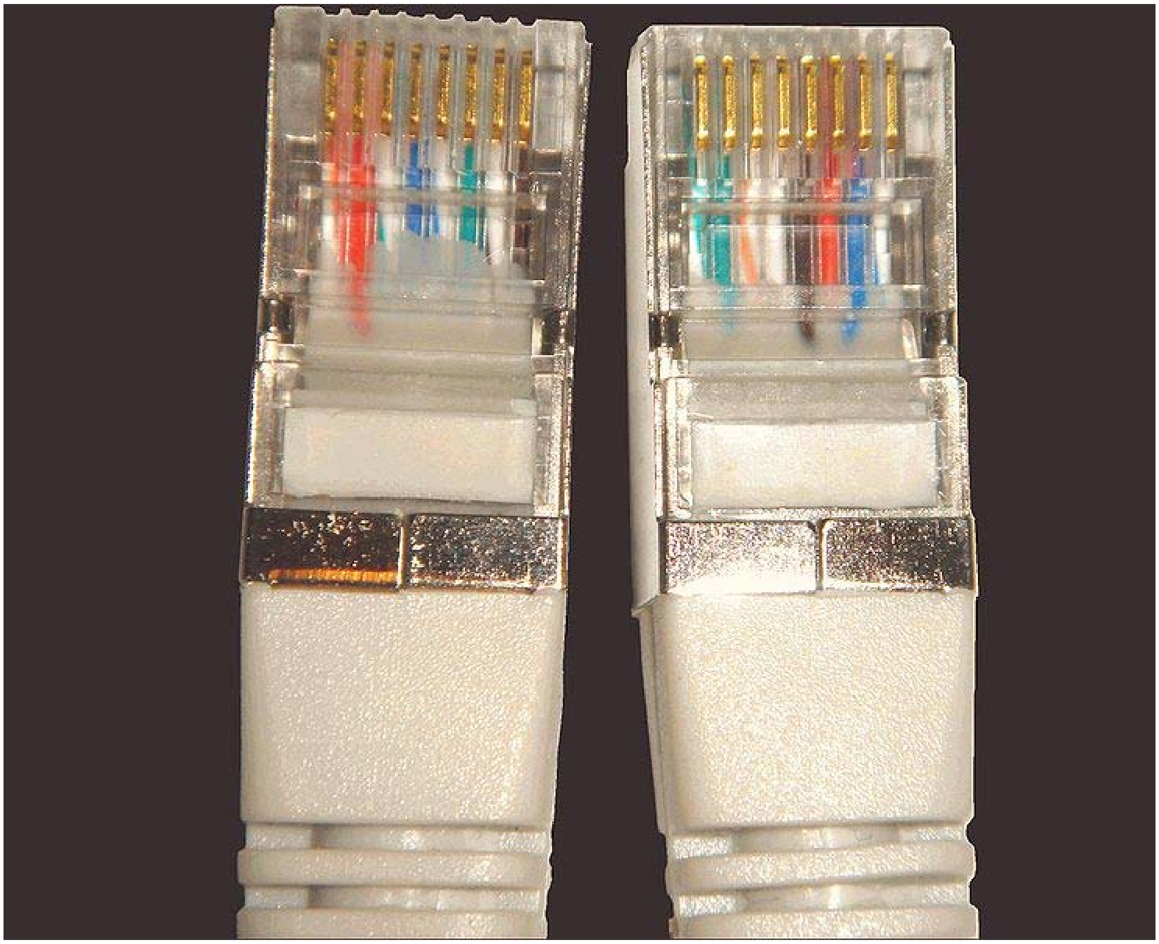
One terminal device may be connected directly to another without the use of a switch or hub, but in that case the crossover must be done externally in the cable or modular crossover adapter. Since 10BASE-T and 100BASE-TX use pairs 2 and 3, these two pairs must be swapped in the cable. This is a *crossover cable*. A crossover cable must also be used to connect two internally crossed devices (e.g., two hubs) as the internal crossovers cancel each other out.

Because the only difference between the T568A and T568B pin/pair assignments are that pairs 2 and 3 are swapped, a crossover cable may be envisioned as a cable with one modular connector following T568A and the other T568B. Such a cable will work for 10BASE-T or 100BASE-TX. Gigabit Ethernet (and an early Fast Ethernet variant, 100BASE-T4) use all four pairs and also requires the other two pairs (1 and 4) to be swapped.

8P8C modular crossover adapter



T568B wired connector



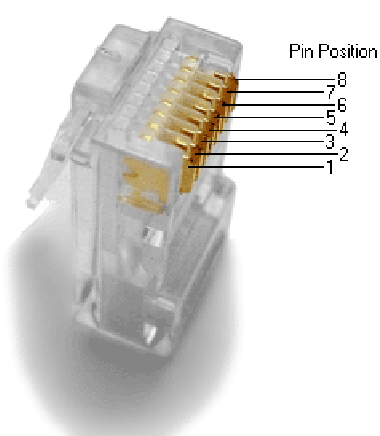
Gigabit T568B crossover cable ends

Crossover cable pinouts

Two pairs crossed, two pairs uncrossed
10BASE-T or 100BASE-TX crossover

Pin	Connection 1: T568A			Connection 2: T568B		
	signal	**pair**	**color**	**signal**	**pair**	**color**
1	BI_DA+	3	white/green stripe	BI_DB+	2	white/orange stripe
2	BI_DA-	3	green solid	BI_DB-	2	orange solid
3	BI_DB+	2	white/orange stripe	BI_DA+	3	white/green stripe
4		1	blue solid		1	blue solid
5		1	white/blue stripe		1	white/blue stripe

Pins on plug face



6	BI_DB-	2	orange solid	BI_DA-	3	green solid
7		4	white/brown stripe		4	white/brown stripe
8		4	brown solid		4	brown solid

Certain equipment or installations, including those in which phone and/or power are mixed with data in the same cable, may require that the "non-data" pairs 1 and 4 (pins 4, 5, 7 and 8) remain un-crossed.

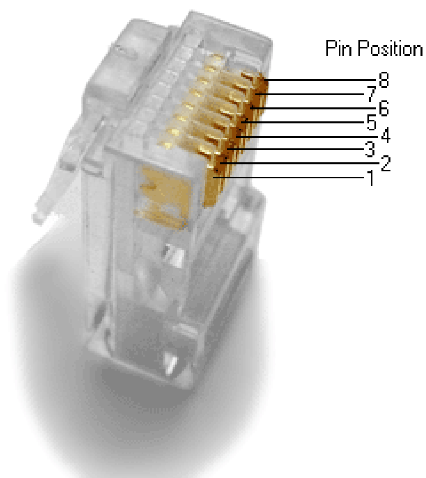
Gigabit T568A crossover

All four pairs crossed

10BASE-T, 100BASE-TX, 100BASE-T4 or 1000BASE-T crossover (shown as T568A)

Pin	Connection 1: T568A signal	pair	color	Connection 2: T568A Crossed signal	pair	color
1	BI_DA+	3	white/green stripe	BI_DB+	2	white/orange stripe
2	BI_DA-	3	green solid	BI_DB-	2	orange solid
3	BI_DB+	2	white/orange stripe	BI_DA+	3	white/green stripe
4	BI_DC+	1	blue solid	BI_DD+	4	white/brown stripe
5	BI_DC-	1	white/blue stripe	BI_DD-	4	brown solid
6	BI_DB-	2	orange solid	BI_DA-	3	green solid
7	BI_DD+	4	white/brown stripe	BI_DC+	1	blue solid
8	BI_DD-	4	brown solid	BI_DC-	1	white/blue stripe

Pins on plug face



Gigabit T568B crossover

All four pairs crossed

10BASE-T, 100BASE-TX, 100BASE-T4 or 1000BASE-T crossover (shown as T568B)

Pin	Connection 1: T568B signal	pair	color	Connection 2: T568B Crossed signal	pair	color
1	BI_DA+	2	white/orange stripe	BI_DB+	3	white/green stripe
2	BI_DA-	2		BI_DB-	3	

Pins on plug face

			orange solid			green solid
3	BI_DB+	3	white/green stripe	BI_DA+	2	white/orange stripe
4	BI_DC+	1	blue solid	BI_DD+	4	white/brown stripe
5	BI_DC-	1	white/blue stripe	BI_DD-	4	brown solid
6	BI_DB-	3	green solid	BI_DA-	2	orange solid
7	BI_DD+	4	white/brown stripe	BI_DC+	1	blue solid
8	BI_DD-	4	brown solid	BI_DC-	1	white/blue stripe

In practice, it does not matter if Ethernet cables are wired as T568A or T568B, just so long as both ends follow the same wiring format. Typical commercially available "pre-wired" cables can follow either format depending the manufacturer. What this means is that one manufacturer's cables are wired one way and another's the other way, yet both are correct and will work. In either case, T568A or T568B, a normal (un-crossed) cable will have **both** ends wired according to the layout in the *Connection 1* column.

Although this crossover is called out in the Gigabit Ethernet standard, all Gigabit PHYs feature an auto-MDIX capability and are designed for compatibility with the existing 100BASE-TX crossovers. The IEEE-specified Gigabit crossover is generally seen as unnecessary.

Automatic crossover

If one of two connected devices has the automatic MDI/MDI-X configuration feature there is no need anymore for crossover cables. This will obsole the uplink/normal ports and manual selector switches found on many older hubs and switches.

Although Auto-MDIX is specified as an optional feature in the 1000BASE-T standard, in practice it is implemented on all 1000BASE-TX interfaces.

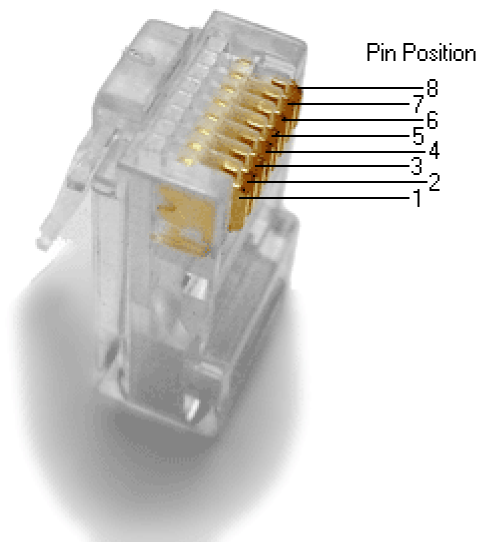
Modern switches automatically apply an internal crossover when necessary. Besides the eventually agreed upon *Automatic MDI/MDI-X*, this feature may also be referred to by various vendor-specific terms including: *Auto uplink and trade*, *Universal Cable Recognition* and *Auto Sensing*.

Chapter-3

Category 5 Cable

Category 5 patch cable in TIA/EIA-568-B wiring

Category 5 cable (**Cat 5**) is a twisted pair high signal integrity cable type. This type of cable is used in structured cabling for computer networks such as Ethernet and ATM, and is also used to carry many other signals such as telephony and video. Most Category 5 cables are unshielded (UTP), relying on the twisted pair design for noise rejection. Category 5 has been superseded by the **Category 5e** specification.



8P8C modular plug pin positioning

TIA/EIA-568-A.1-2001 T568A Wiring

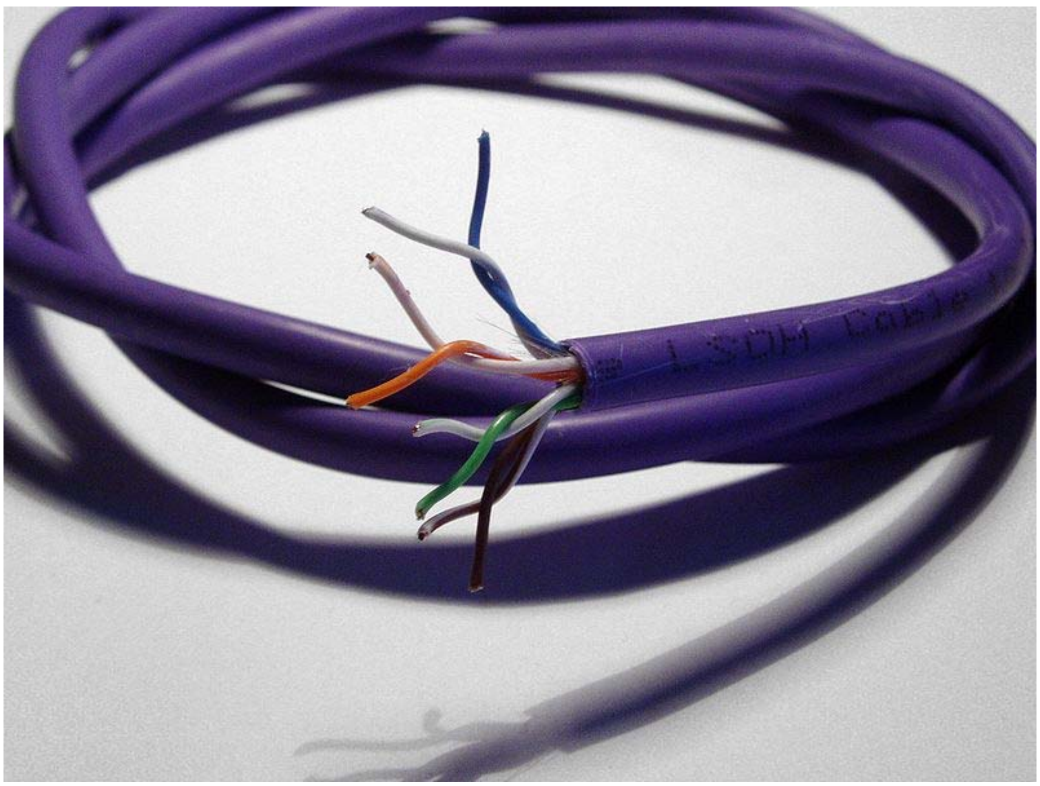
Pin	Pair	Wire	Color
1	3	1	white/green
2	3	2	green
3	2	1	white/orange
4	1	2	blue
5	1	1	white/blue
6	2	2	orange
7	4	1	white/brown
8	4	2	brown

TIA/EIA-568-B.1-2001 T568B Wiring

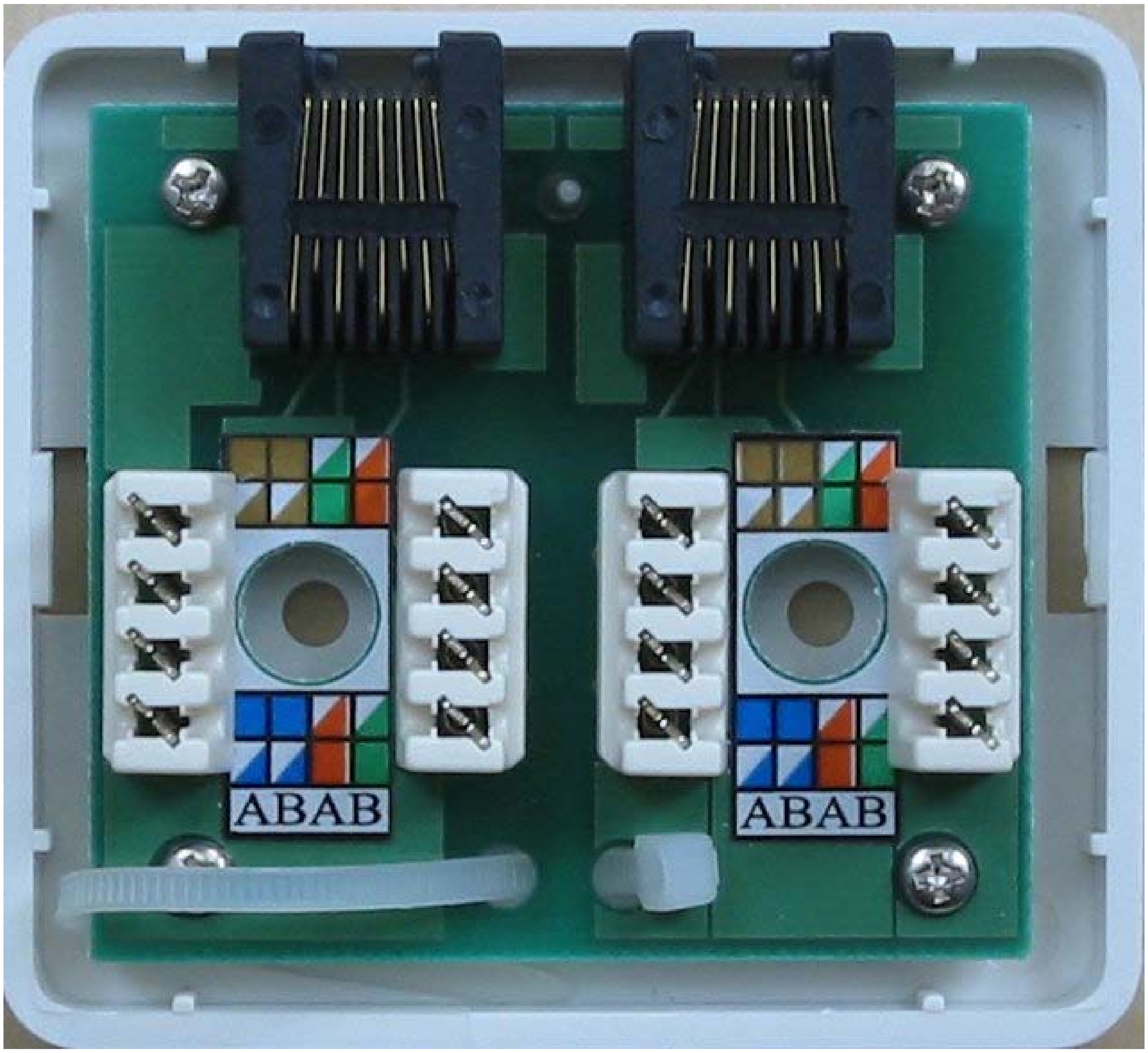
Pin	Pair	Wire	Color
1	2	1	white/orange
2	2	2	orange
3	3	1	white/green
4	1	2	blue
5	1	1	white/blue
6	3	2	green
7	4	1	white/brown
8	4	2	brown

USOC/RJ61 Wiring

Pin	Pair	Wire	Color
1	4	tip	white/brown
2	3	tip	white/green
3	2	tip	white/orange
4	1	ring	blue
5	1	tip	white/blue
6	2	ring	orange
7	3	ring	green
8	4	ring	brown



Partially stripped cable showing the twisted pairs.



A Cat 5e Wall outlet showing the two wiring schemes: A for T568A, B for T568B.

Cable standard

The specification for Category 5 cable was defined in ANSI/TIA/EIA-568-A, with clarification in TSB-95. These documents specified performance characteristics and test requirements for frequencies of up to 100 MHz.

Category 5 cable is not limited to 4 pairs. Backbone applications involve using up to 100 pairs as noted in ANSI/TIA/EIA-568-B-2 standard for backbone applications. This use of balanced lines helps preserve a high signal-to-noise ratio despite interference from both external sources and other pairs (this latter form of interference is called crosstalk). It is most commonly used for 100 Mbit/s networks, such as 100BASE-TX Ethernet, although IEEE 802.3ab defines standards for 1000BASE-T – Gigabit Ethernet over category 5 cable. Each of the four pairs in a Cat 5 cable has differing precise number of twists per metre based on prime numbers to minimize crosstalk between the pairs. On average there are 6 twists per 5 centimetres. The pairs are made from 24 gauge (AWG) copper wires within the cables.

Connectors and other information

The cable exists in both stranded and solid conductor forms. The stranded form is more flexible and withstands more bending without breaking and is suited for reliable connections with insulation piercing connectors, but makes unreliable connections in insulation-displacement connectors. The solid form is less expensive and makes reliable connections into insulation displacement connectors, but makes unreliable connections in insulation piercing connectors. Taking these things into account, building 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. Outer insulation is typically PVC or LSOH.

Cable types, connector types and cabling topologies are defined by TIA/EIA-568-B. Nearly always, 8P8C modular connectors, often incorrectly referred to as "RJ-45", are used for connecting category 5 cable. The specific category of cable in use can be identified by the printing on the side of the cable.

The cable is terminated in either the T568A scheme or the T568B scheme. Canada and Australia use the T568A standard, and the United States commonly uses T568B scheme. It really doesn't make any difference which is used as long as you use only one of the standards so all connections are the same at your location to avoid confusion and potential problems. Mixed cable types should not be connected in series as the impedance per pair differs slightly and may cause signal degradation.

Conductors required

10BASE-T (IEEE) and 100BASE-TX (IEEE) Ethernet connections require two cable pairs. 1000BASE-T (IEEE) and 1000BASE-TX (TIA/EIA-854, requiring category 6 cabling) Ethernet connections require four cable pairs. Four pair cable is by far the most commonly available type.

Bending radius

Most Cat 5 cables can be bent at a radius approximately 4 times the diameter of the cable.

Maximum cable segment length

According to the ANSI/TIA/EIA standard for category 5e cable, (TIA/EIA 568-5-A) the maximum length for a cable segment is 100 meters (328 feet). If longer runs are required, the use of active hardware such as a repeater, or a switch, is necessary. The specifications for 10baseT networking specify a 100 metre length between active devices. This allows for 90 metres of fixed cabling, two connectors and two patch leads of 5 metres, one at each end. In practice longer lengths are possible. Experiments show that a full 305 metre drum of cable is well above the practical limit, but that reliable transmission with 200 m is often possible.

Characteristics

Electrical characteristics for Cat 5e UTP

Property	Nominal Value	Tolerance	Unit
Characteristic impedance @ 100 MHz	100	± 15	Ω
Nominal characteristic impedance @ 100 MHz	100	± 5	Ω
DC-Loop resistance	≤ 0.188		Ω/m
Propagation speed	0.64		c
Propagation delay	4.80-5.30		ns/m
Delay skew < 100 MHz	< 0.20		ns/m
Capacitance at 800 Hz	52		pF/m
Inductance	525		nH/m
Cutoff frequency	50323		Hz
Max tensile load, during installation	100		N
Wire size	AWG-24 (0.205 mm²)		
Insulation thickness	0.245		mm
Maximum current per conductor	0.577		A
Temperature operating	-55 to +60		°C

Dielectric

Example materials used as dielectric in the cable

Acronym	Material
PVC	Polyvinyl Chloride
PE	Polyethylene
FP	Foamed polyethylene
FEP	Teflon/fluorinated ethylene propylene
FFEP	Foamed Teflon/fluorinated ethylene propylene
AD/PE	Air dielectric/polyethylene

Individual twist lengths

By altering the length of each twist, crosstalk is reduced, without affecting the characteristic impedance.

Pair color	[cm] per turn	Turns per [m]

Green	1.53	65.2
Blue	1.54	64.8
Orange	1.78	56.2
Brown	1.94	51.7

Environmental ratings

US & Canada fire certifications

Class	Acronym	Standards
CMP	Communications Plenum	CSA FT7 or NFPA 262 (UL 910)
CMR	Communications Riser	UL 1666
CMG	Communications General purpose	CSA FT4
CM	Communications	UL 1685 (UL 1581, Sec. 1160) Vertical-Tray
CMX	Communications Residential	UL 1581, Sec. 1080 (VW-1)
CMH		CSA FT1

CMR (**Com**munications **R**iser), insulated with high-density polyolefin and jacketed with low-smoke polyvinyl chloride (PVC) can be replaced by a CMP (**Com**munications **P**lenum), insulated with flourinated 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.

Any cable which 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 which may channel water into sensitive indoor equipment. This can often be solved by adding a drip-loop at the bottom of the run of cable.

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.

Shielded cables (FTP/STP) are useful for environments where proximity to power cables, RF equipment, or high power equipment may introduce crosstalk, and can also be used where interference with radio receivers or where eavesdropping likelihood should be minimized.

Other issues

Copper-clad aluminium

The American market was flooded with copper clad cable imported mostly from China and falsely presented in the market as being a 100% copper Cat 5e cable. With less copper involved in the manufacturing process, the cost to the consumer is lower, yet the consumer is not getting a true 100% copper Cat 5e cable.

Installation of copper clad aluminium Cat 5e wire was proven — by low-voltage contractors in the Southern California market, where this cable first arrived — to have poor test results and often did not pass the Category 5e transmission standard. Since copper conducts electricity better than aluminium, signal strength has shown to be very weak over long runs using this substandard cable.

Additionally, some manufacturers falsely represented their Cat 5e cable conductors as being 24 AWG. In actuality, a 26 AWG conductor is being sold and is hard to detect unless further examination beneath the sheath of the conductor is performed. A 26 AWG Cat 5e cable will not make proper contact on Cat 5e jack modules as most jack modules require 22 or 24 AWG per the specification and qualified connectors.

The United States Federal Government will not accept bids from China for Cat 5e cable due to China being absent from the Trade Agreements Act of 1979. In general, a product is only "TAA compliant" if it is made in the United States or a "Designated Country".

Non-data use

Although designed for Ethernet data transmission, CAT5 cable has also been used informally for analog signals: a balanced audio 'digi-snake' or 'digital snake' cable - but without the complication of audio-digital-audio conversion. It can also be used with video signals (CCTV), with Baluns to convert from/to unbalanced signals at each end.

Chapter-4

Category 6 Cable and Category 7 Cable

Category 6 cable

Category 6 cable, commonly referred to as **Cat 6**, is a cable standard for Gigabit Ethernet and other network Physical Layers that is backward compatible with the Category 5/5e and Category 3 cable standards. Compared with Cat 5 and Cat 5e, Cat 6 features more stringent specifications for crosstalk and system noise. 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).

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 distance as previous protocols.

Category 6

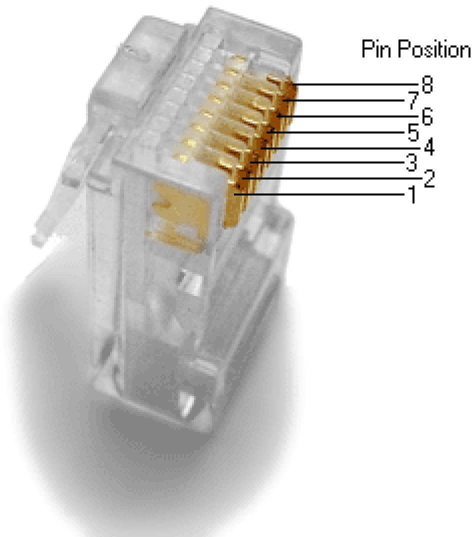
Like most earlier cables, Category 6 cable contains four twisted wire pairs. Although it is sometimes made with 23 AWG wire, the increase in performance with Cat 6 comes mainly from better insulation; 22 to 24 AWG copper is allowed if the ANSI/TIA-568-B.2-1 performance specifications are met. Cat 6 patch cables are normally terminated in 8P8C modular connectors. Attenuation, NEXT (near end crosstalk), and PSNEXT (power sum NEXT) in Cat 6 cable and connectors are all significantly lower than Cat 5 or Cat 5e, which also uses 24 AWG wire.

The heavier insulation in some Cat 6 cables makes them too thick to attach to 8P8C connectors without a special modular piece, resulting in a technically out-of-compliance assembly.

Connectors use either T568A or T568B pin assignments; the choice is arbitrary provided both ends of a cable are the same.

If Cat 6 rated patch cables, jacks, and connectors are not used with Cat 6 wiring, overall performance is degraded to that of the cable or connector.

Because the conductor sizes are generally the same, Cat 6 jacks may also be used with Cat 5e cable.



Pins on 8P8C plug face

8P8C Wiring (T568A termination)

Pin	Pair	Wire	Color
1	3	1	white/green
2	3	2	green
3	2	1	white/orange
4	1	2	blue
5	1	1	white/blue
6	2	2	orange
7	4	1	white/brown
8	4	2	brown

8P8C Wiring (T568B termination)

Pin	Pair	Wire	Color
1	2	1	white/orange
2	2	2	orange
3	3	1	white/green
4	1	2	blue
5	1	1	white/blue

6	3	2	green
7	4	1	white/brown
8	4	2	brown

USOC/RJ61 Wiring

Pin	Pair	Wire	Color
1	4	1	white/brown
2	3	1	white/green
3	2	1	white/orange
4	1	2	blue
5	1	1	white/blue
6	2	2	orange
7	3	2	green
8	4	2	brown

Category 6 cable can be identified by the printing on the side of the cable sheath.

Category 6a

The latest standard from the TIA for enhanced performance standards for twisted pair cable systems was defined in February 2008 in ANSI/TIA/EIA-568-B.2-10. **Category 6a** (or **Augmented Category 6**) is defined at frequencies up to 500 MHz—twice that of Cat. 6.

Category 6a performs at improved specifications, particularly in the area of alien crosstalk as compared to Cat 6 UTP 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 which are based on the American TIA standard.

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 100% increase of near-end crosstalk noise reduction when measured in absolute magnitudes.

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. Broadly speaking the ISO standard for Cat6A is the highest, followed by the European standard and then the American.

Maximum length

When used for 10/100/1000BASE-T, the maximum allowed length of a Cat 6 cable is 100 meters (330 ft). This consists of 90 meters (300 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. Since stranded cable has higher attenuation than solid cable, exceeding 10 metres of patch cabling will reduce the permissible length of horizontal cable.

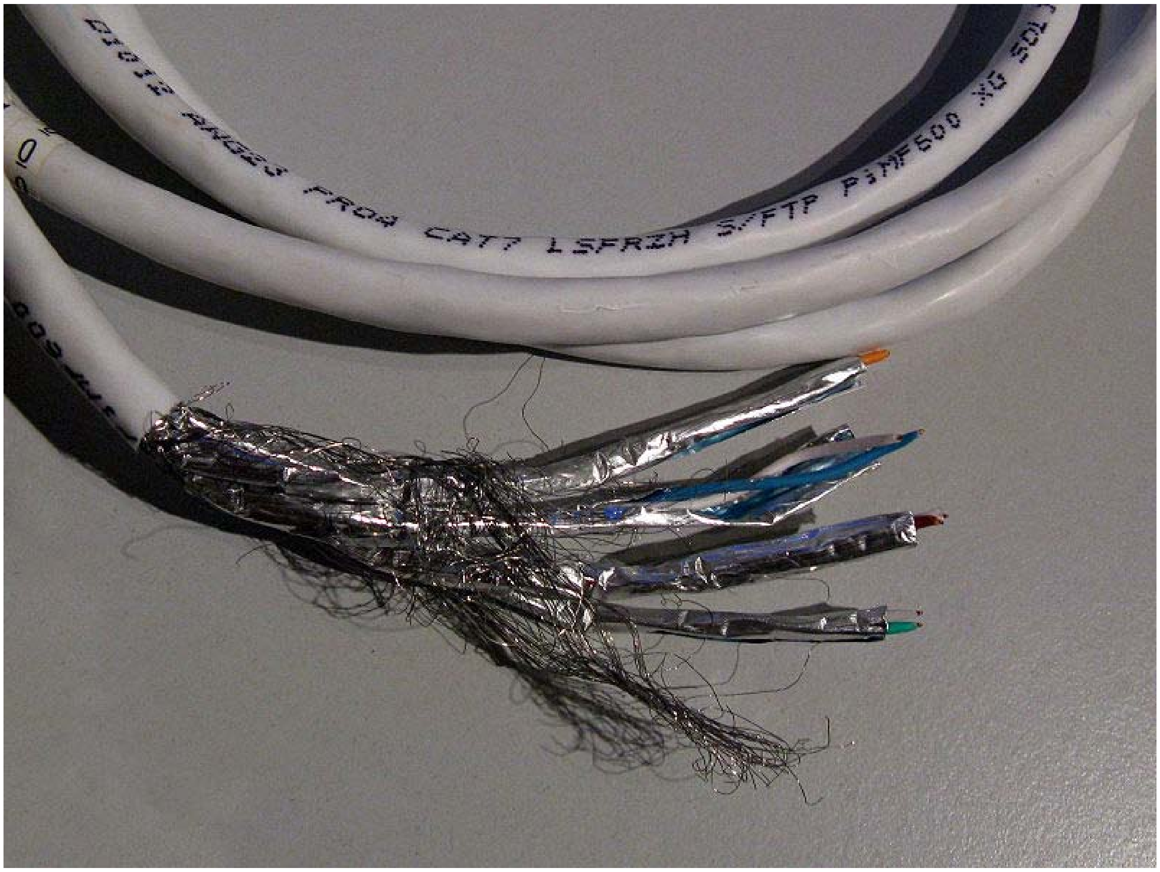
When used for 10GBASE-T, Cat 6 cable's maximum length is 55 meters (180 ft) in a favourable alien crosstalk environment, but only 37 meters (121 ft) in a hostile alien crosstalk environment such as when many cables are bundled together. 10GBASE-T runs of up to 100 meters (330 ft) are permissible using Cat 6a.

Installation caveats

Category 6 and 6a cable must be properly installed and terminated to meet specifications. Incorrect installation practices include kinking or bending the cable too tightly. The cable bend radius should be no less than 4 times the outer diameter of the cable. Incorrect termination practices include untwisting the wire pairs or stripping the outer jacket back more than 1/2 inch.

All shielded cables must be grounded for safety and effectiveness. A continuous shield connection maintained from end to end. Ground loops develop when there is more than one ground connection and the difference in common mode voltage potential at these ground connections introduces noise into the cabling.

Category 7 cable



Category 7 cable

Category 7 cable (**Cat 7**), (ISO/IEC 11801:2002 category 7/class F), is a cable standard for Ethernet and other interconnect technologies that can be made to be backward compatible with traditional Cat 5 and Cat 6 Ethernet cable. Cat 7 features even more strict specifications for crosstalk and system noise than Cat 6. To achieve this, shielding has been added for individual wire pairs and the cable as a whole. Besides the foil shield, the twisting of the pairs and number of turns per inch causes RF shielding and protects from crosstalk. Category 7 is recognized for all the country organizations members of ISO.

The Cat 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. Cat 7 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, Cat 7 cable is rated for transmission frequencies of up to 600 MHz.

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 or TERA in order to function on Cat 6a. Due to lack of support for the 8P8C connector, Category 7 is not recognized in TIA/EIA-568.

Category 7a

Category 7a (or **Augmented Category 7**) is defined at frequencies up to 1000 MHz, suitable for multiple applications including CATV (862 MHz). Simulation results have shown that 40 Gigabit Ethernet is possible at 50 meters and 100 Gigabit Ethernet is possible at 15 meters. Mohsen Kavehrad and researchers at The Pennsylvania State University believe that either 32 nm or 22 nm circuits will allow for 100 Gigabit Ethernet at 100 meters.

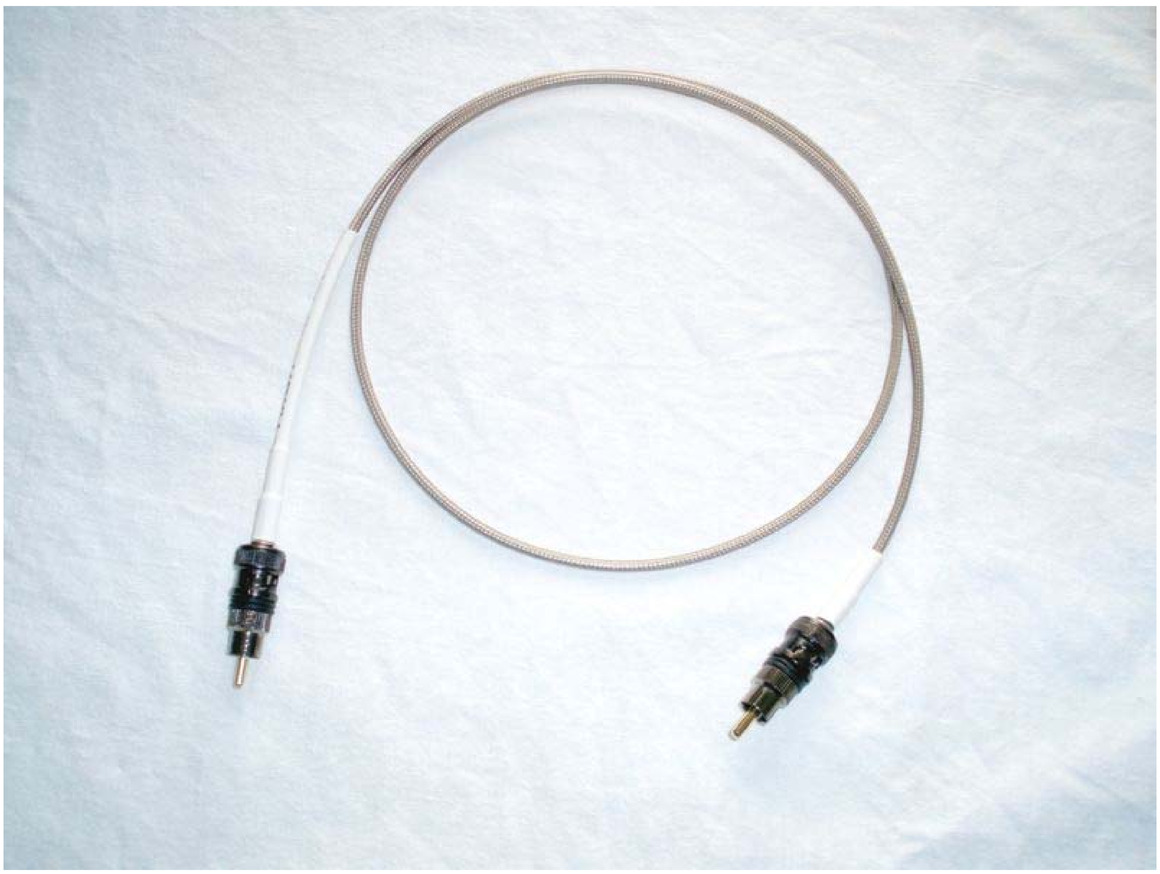
However, similar studies in the past have shown that Cat5e could support 10 Gbit/s, so these should be read with caution. Furthermore, the IEEE has chosen not to include Cat7a for 40 Gbit/s or 100 Gbit/s in the new 802.3ba standard ratified in June 2010. It may in the future, but there is absolutely no guarantee that such applications will ever exist.

Cat7a is currently in ISO standards for channel performance in Amendment 1, recently component performance has been ratified in Amendment 2. The formal names are ISO 11801 Amendment 1 (2008) and ISO 11801 Amendment 2 (2010). Category 7a is not recognized in TIA/EIA-568.

Chapter-5

High-end Audio Cables and Line Level

High-end audio cables



High-end coaxial audio cable.

High-end audio cables are cables which are claimed to improve the sound quality of high-fidelity audio systems. Cables between components are called interconnects. Speaker wires carry the signal between the amplifier and speakers.

For analog interconnecting cables, basic system frequency response can be calculated from the electrical properties of the cables, and components on either side of the cables. These electrical properties include resistance, capacitance, and inductance. For small-signal applications the degree of shielding is also important. All of these qualities are taken into account in the design of commercial and broadcast cables. High-end cables for the audiophile market often involve intricate construction geometries and exotic materials such as silver and oxygen-free, long-crystal, high-purity copper.

Cables carrying digital signals, such as S/PDIF and HDMI, are effectively immune to signal degradation for the short lengths used in consumer audio. HDMI uses error correction which makes errors even less likely.

Quality debate

There is debate among audiophiles surrounding the impact that high-end cables have on audio systems with audibility of the changes central to the discussion. Bill Whitlock, president of Jensen Transformers, has written that "no other product is as shrouded in hype and mystery as the audio cable!" Whitlock continues by saying that the high-end segment of the audio industry "abounds with misinformation, myth, and mysticism." There are claims that, even among audiophiles, in a double-blind test it is impossible to distinguish extremely expensive, exotic speaker cables from ordinary lamp cords or budget 12AWG copper speaker wire.

James Randi, a stage magician and scientific skeptic best known as a challenger of paranormal claims and pseudoscience, offered a prize of one million dollars to anyone who could prove his or her ability to distinguish an expensive high-end audio cable from an ordinary audio cable by means of a controlled listening test. Michael Fremer of Stereophile magazine took the challenge, but satisfactory testing conditions could not be agreed upon, and the test did not take place. In rigorous tests performed under controlled circumstances, listeners have not been able to prove there is any audible difference between high end and cheap cables.

Analog signal cables

Whitlock defines a good analog audio signal cable for unbalanced (consumer) applications as one that has low capacitance and very low shield resistance. Signal cables should be kept as short as possible, and longer cables should be ones with heavy gauge-equivalent wiring. "The *only* property of a cable that has any significant effect on audio noise coupling is shield resistance."

Digital cables

One of the more contentious areas is in digital cable design, with high end cables being sold with claims of "distortion-free signal transfer." Some have argued that since the bit rates (approximately 1 Mbit/s) and distance traveled are considerably lower than for other data transfer technologies such as gigabit ethernet, any cable appropriately matched to the correct impedance requirement is sufficient. Others claim that jitter caused by imperfect impedance matching is very detrimental to the audio signal and the most substantial shortcoming of digital audio. This signal deterioration comes about not through corruption of the digital information itself, but instead in the process required to recover the clock signal for the DAC performing the analog conversion. Mitigation strategies have been proposed, including digital interconnect cables which use dedicated clock lines so as to avoid data-dependent jitter or to obviate clock recovery altogether. However, since pure digital applications can successfully transfer data streams with no corruption whatsoever at speeds more than 1000 times greater than digital audio, this is very unlikely to be the worthwhile. A more promising route would be an improved protocol with better error correction.

Speaker wire

Another area of debate is speaker wire "quality". While some speaker wire marketers claim audible improvement with design or exotic materials, skeptics say that a few meters of speaker wire from the power amplifier to the binding posts of the loudspeakers cannot possibly have much influence because of the greater influence from complex crossover circuits found in most speakers and particularly from the speaker driver voice coils that have several meters of very thin wire. There is however agreement that the overall resistance of the speaker wire should not be too high.

An accepted guideline is that the wire impedance should not exceed 5% of the entire circuit. For a given material, resistance is a function of length and thickness (specifically of the ratio of length to cross-sectional area). For this reason, lower impedance speakers require lower resistance speaker wire. Longer cable runs need to be even thicker. Once the 5% guideline is met, thicker wire will not provide any improvement.

Roger Russell—a former engineer and speaker designer for McIntosh Labs—details how expensive speaker wire brand marketing misinforms consumers in his online essay called *Speaker Wire - A History.* He writes, "The industry has now reached the point where [wire] resistance and listening quality are not the issues any more, although listening claims may still be made....The strategy in selling these products is, in part, to appeal to those who are looking to impress others with something unique and expensive."

Mains power cables

Another controversial area of audio cabling is that of mains power cables. Products exist that claim to improve the sound or picture with a short length of expensive oxygen-free copper or silver cable connected from the wall socket to the equipment. More scientific arguments have been presented, such as building RFI (Radio Frequency Interference) filters into the cables as well as shielding against EMI (Electro-Magnetic Interference) can produce a cleaner noise free supply and hence a better sound or picture quality, if the design of the power supply in the equipment is poor. Although subjective tests have occasionally confirmed this, little objective proof has been given. One critique of high end power cable questions how a short strand of expensive cable can improve upon electricity delivered by miles of standard electricity transmission equipment outside and inside a home. Given this paradox, he then asks, "how short does the [specialized] wire have to be made before differences can no longer be heard?"

Line level

Line level is a term used to denote the strength of an audio signal used to transmit analog sound between audio components such as CD and DVD players, TVs, audio amplifiers, and mixing consoles, and sometimes MP3 players.

In contrast to line level, there are weaker audio signals, such as those from microphones and instrument pickups, and stronger signals, such as those used to drive headphones and loudspeakers. The strength of the various signals does not necessarily correlate with the output voltage of a device; it also depends on the source's output impedance, or the amount of current available to drive different loads.

Overview

Consumer electronic devices concerned with audio (for example Sound cards) often have a connector labeled "*line in*" and/or "*line out*". Line out provides an audio signal output and line in receives a signal input. The line in/out connections on a computer sound card are generally unbalanced, with a TRS connector of 6.35 mm (1/4"), 3.5 mm (1/8" miniature) or 2.5 mm (3/32" subminiature). The connections on most other consumer equipment use RCA jacks. In most cases changing the volume setting on the source equipment does not vary the strength of the line out signal.

Nominal levels

A line level describes a line's nominal signal level as a ratio, expressed in decibels, against a standard reference voltage. The nominal level and the reference voltage against which it is expressed depend on the line level being used. While the nominal levels themselves vary, only two reference voltages are common: decibel volts [dBV] for consumer applications, and decibels unloaded [dBu] for professional applications.

The reference voltage for the decibel volt (0 dBV) is 1 V_{RMS}, which is the voltage required to produce 1 milliwatt [mW]; of power across a 1 kiloohm [kΩ] load. The reference voltage for the decibel unloaded (0 dBu) is the voltage required to produce 1 mW of power across a 600 Ω load (approximately 0.7746 V_{RMS}).

The most common nominal level for consumer audio equipment is −10 dBV, and the most common nominal level for professional equipment is 4 dBu. By convention, nominal levels are always written with an explicit sign symbol. Thus 4 dBu is written as +4 dBu.

Expressed in absolute terms, a signal at −10 dBV is equivalent to a sine wave signal with a peak amplitude of approximately 0.447 volts, or any general signal at 0.316 volts root mean square (V_{RMS}). A signal at +4 dBu is equivalent to a sine wave signal with a peak amplitude of approximately 1.737 volts, or any general signal at approximately 1.228 V_{RMS}.

Peak to peak values are twice the peak values.

When digitised, the number of bits must be assigned to the entire peak to peak range with both negative and positive voltage values. That requires the use of one bit for a sign (+/−) leaving N−1 bits for the data values. Hence a 16 bit (CD standard) only has 15 bits for data which gives 2^{15} (32,768 different values) for both positive and negative voltage values. 24 bits means there are 2^{23} levels (8,388,608 levels) and 32 bits yield 2^{31} (22,147,483,650 levels).

Digitised values run from 0 for zero voltage up to the maximum *designed* value for the circuit. There is no absolute maximum, and it depends on the circuit design.

Line levels and their nominal voltage levels.

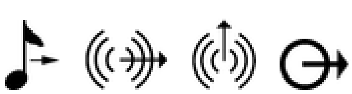
Use	**Nominal level**	**Nominal level, V_{RMS}**	**Peak Amplitude, V_{PK}**
ARD, Germany	+6 dBu	1.550 (approximate)	2.192 (approximate)
USA professional audio	+4 dBu	1.228 (approximate)	1.737 (approximate)
Consumer audio	−10 dBV	0.316	0.447

The line level signal is an alternating current signal, meaning that its voltage varies for example from −2.192 V to +2.192 V.

Impedances

Impedance bridging is employed to ensure that very little power is transferred and the line in circuit does not load down the output of the other device. When a line out signal, with its output impedance of around 100 Ω, is connected to a line in with an input impedance of 10 kΩ, most of the voltage appears across the input resistance and almost none of the voltage is dropped across the output. In effect, the output impedance of the source, and the input impedance of the line in form a voltage divider with a shunt element that is large relative to the size of the series element, which ensures that little of the signal is shunted to ground and that current requirements are minimized.

Line out

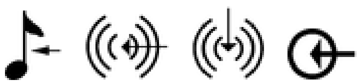


Line-out symbol. PC Guide color Lime green.

The signal out of line out remains at a constant level, regardless of the current setting of the volume control. You can connect recording equipment to line out and record the signal, without having to listen to it through the device's speaker, and without the loudness of the recording changing if you change the volume control setting of the device while you are recording.

The impedance is around 100 Ω, the voltage can reach 2 volts peak-to-peak with levels referenced to -10 dBV (300 mV) at 10 kΩ, and frequency response of most modern equipment is advertised as 20 Hz - 20 000 Hz (although other factors influence frequency response). This impedance level is much higher than the usual 4 - 8 Ω of a speaker or 32 Ω of headphones, such that a speaker connected to line out essentially short circuits the op-amp. Even if the impedances would match, yielding the theoretical maximum power transfer of 50%, the power supplied through line out is not enough to drive a speaker.

Line in


Line-in symbol. PC Guide color Light blue.

Line in expects the kind of voltage level and impedance that line out provides. You can typically connect the line out connector of one device with the line in of another. However, doing this with a straight cable directly connected to both devices and having both devices on AC power, you may run into a ground loop; although some devices provide isolation by using an opto-isolator, which does not create a physical connection between the devices.

A line input has a high impedance of around 10 kΩ, as is often labeled as "Hi-Z" input (Z being the designator for impedance).

Line level in traditional signal paths

Acoustic sounds (such as voices or musical instruments) are often recorded with transducers (microphones and pickups) that produce weak electrical signals. These signals must be amplified to line level, where they are more easily manipulated by other devices such as mixing consoles and tape recorders. Such amplification is performed by a device known as a preamplifier or "preamp". After manipulation at line level, signals are then typically sent to a device known as a power amplifier, where they are amplified to levels that can drive headphones or loudspeakers, which convert the signals back into sounds that can be heard through the air.

Most phonographs also have a low output level and require a preamp; typically, a home stereo amplifier will have a special phono input with a built-in preamp, which is much more sensitive than a line-level input. The phono preamp applies RIAA equalization to the reproduced sound.

Information transfer

These are voltage signals (as opposed to current signals) and it is the signal information (voltage) that is desired, not power to drive a transducer, such as a speaker or antenna. The actual information that is exchanged between the devices is the variance in voltage; it is this alternating voltage signal that conveys the information, making the current irrelevant.

Chapter-6

Twin-lead

Twin-lead cable is a two-conductor ribbon cable used as a transmission line to carry radio frequency (RF) signals.

300 ohm Twin-lead

Characteristics and uses

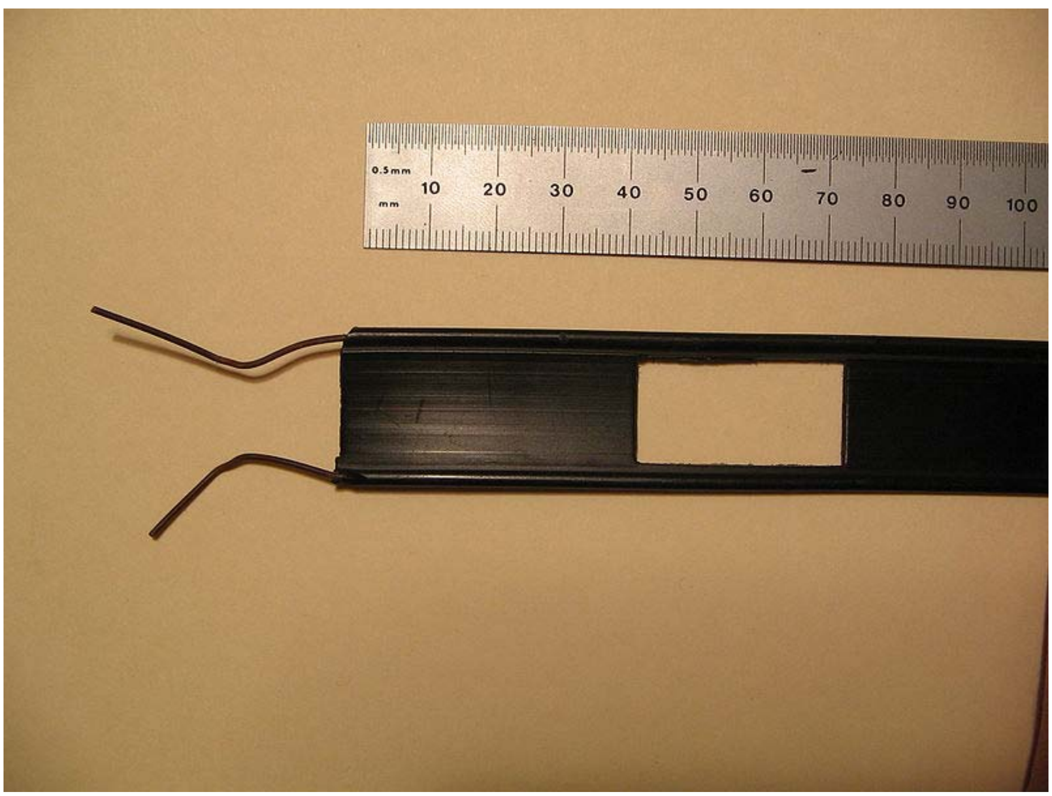
A 300-to-75-ohm balun, showing twin-lead on the right hand side

Twin-lead is constructed of two multistranded copper or copperclad 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 wire is usually 20 or 22 gauge, about 7.5 mm (0.30 inches) apart.

Twin lead and other types of parallel 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.

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.

Ladder line



450 Ohm "Ladder line"

Commercially manufactured ladder line or "window line" is a type of transmission line similar to twin-lead for balanced connection of antennas. Ladder line is constructed as a pair of evenly spaced wires with supportive plastic webbing holding the wires apart. The plastic webbing has windows cut in it to reduce its dielectric effect and reduce loss in the transmission line. The alternating webbing and windows gives ladder line its characteristic look and name.

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

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.

Impedance matching

As a transmission line, transmission efficiency will be maximum when the impedance of the antenna, the 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 2:1 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 asymmetric 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 optimum 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.

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

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

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

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

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

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

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

where Z_0 is the impedance of free space (approximately 377 Ω), ε_r 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

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

The separation needed to achieve a given characteristic impedance is therefore

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

Typical properties

Some electrical properties of twin-lead cable:

		Characteristic Impedance	
		300 Ω	**75 Ω**
Capacitance (pF/m)		11.8	20
Propagation speed (% of light)		80%	71%
Loss (dB/100m)	**100 MHz**	3.6	3.6
	300 MHz	7.2	7.2
	500 MHz	10.2	10.2

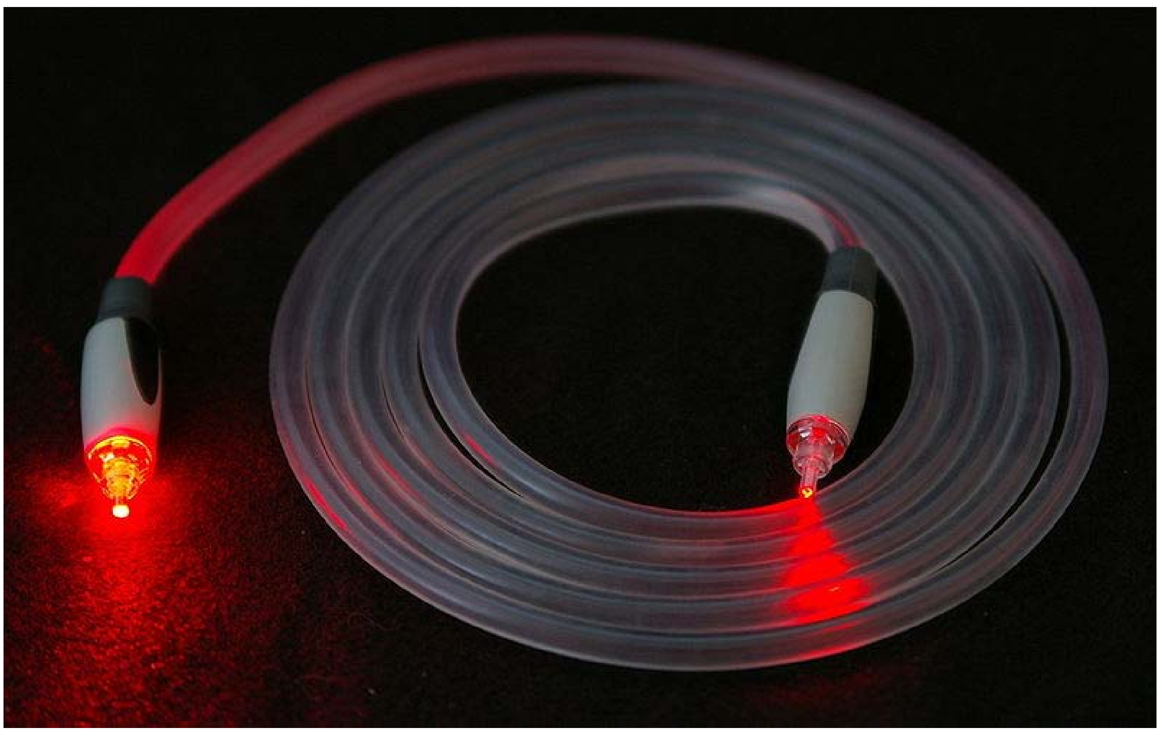
Antennas

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.

Chapter-7

Optical Fiber Cable



A TOSLINK optical fiber cable with a clear jacket. These plastic-fiber cables are used mainly for digital audio connections between devices.

An **optical fiber cable** is a cable containing one or more optical fibers. The optical fiber elements are typically individually coated with plastic layers and contained in a protective tube suitable for the environment where the cable will be deployed.

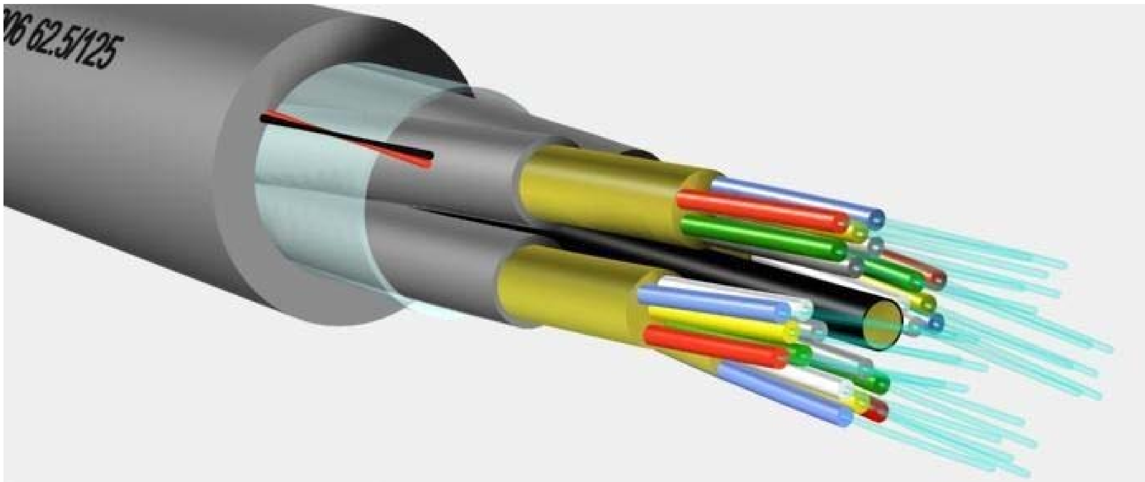
Design

A multi-fiber cable

In practical fibers, the cladding is usually coated with a tough resin *buffer* layer, which may be further surrounded by a *jacket* layer, usually plastic. These layers add strength to the fiber but do not contribute to its optical wave guide properties. Rigid fiber assemblies sometimes put light-absorbing ("dark") glass between the fibers, to prevent light that leaks out of one fiber from entering another. This reduces cross-talk between the fibers, or reduces flare in fiber bundle imaging applications.

Left: LC/PC connectors Right: SC/PC connectors All four connectors have white caps covering the ferrules.

For indoor applications, the jacketed fiber is generally enclosed, with a bundle of flexible fibrous polymer *strength members* like Aramid (e.g. Twaron or Kevlar), in a lightweight plastic cover to form a simple cable. Each end of the cable may be *terminated* with a specialized optical fiber connector to allow it to be easily connected and disconnected from transmitting and receiving equipment.



An optical fiber breakout cable

For use in more strenuous environments, a much more robust cable construction is required. In *loose-tube construction* the fiber is laid helically into semi-rigid tubes, allowing the cable to stretch without stretching the fiber itself. This protects the fiber from tension during laying and due to temperature changes. Loose-tube fiber may be "dry block" or gel-filled. Dry block offers less protection to the fibers than gel-filled, but costs considerably less. Instead of a loose tube, the fiber may be embedded in a heavy polymer jacket, commonly called "tight buffer" construction. Tight buffer cables are offered for a variety of applications, but the two most common are "Breakout" and "Distribution". Breakout cables normally contain a ripcord, two non-conductive dielectric strengthening members (normally a glass rod epoxy), an aramid yarn, and 3 mm buffer tubing with an additional layer of Kevlar surrounding each fiber. The ripcord is a parallel cord of strong yarn that is situated under the jacket(s) of the cable for jacket removal. Distribution cables have an overall Kevlar wrapping, a ripcord, and a 900 micrometer buffer coating surrounding each fiber. These *fiber units* are commonly bundled with additional steel strength members, again with a helical twist to allow for stretching.

A critical concern in outdoor cabling is to protect the fiber from contamination by water. This is accomplished by use of solid barriers such as copper tubes, and water-repellent jelly or water-absorbing powder surrounding the fiber.

Finally, the cable may be armored to protect it from environmental hazards, such as construction work or gnawing animals. Undersea cables are more heavily armored in their near-shore portions to protect them from boat anchors, fishing gear, and even sharks, which may be attracted to the electrical power signals that are carried to power amplifiers or repeaters in the cable.

Modern fiber cables can contain up to a thousand fibers in a single cable, so the performance of optical networks easily accommodates even today's demands for bandwidth on a point-to-point basis. However, unused point-to-point potential bandwidth does not translate to operating profits, and it is estimated that no more than 1% of the optical fiber buried in recent years is actually 'lit'. While unused fiber may not be carrying traffic, it still has value as dark backbone fiber. Companies can lease or sell the unused fiber to other providers who are looking for service in or through an area. Many companies are "overbuilding" their networks for the specific purpose of having a large network of dark fiber for sale. This is a great idea as many cities are difficult to deal with when applying for permits and trenching in new ducts is very costly.

Modern cables come in a wide variety of sheathings and armor, designed for applications such as direct burial in trenches, dual use as power lines, installation in conduit, lashing to aerial telephone poles, submarine installation, or insertion in paved streets. In recent years the cost of small fiber-count pole-mounted cables has greatly decreased due to the high Japanese and South Korean demand for fiber to the home (FTTH) installations.

Cable types

- OFC: Optical fiber, conductive
- OFN: Optical fiber, nonconductive
- OFCG: Optical fiber, conductive, general use
- OFNG: Optical fiber, nonconductive, general use
- OFCP: Optical fiber, conductive, plenum
- OFNP: Optical fiber, nonconductive, plenum
- OFCR: Optical fiber, conductive, riser
- OFNR: Optical fiber, nonconductive, riser
- OPGW: Optical fiber composite overhead ground wire
- ADSS: All-Dielectric Self-Supporting

Jacket material

The jacket material is application specific. The material determines the mechanical robustness, aging due to UV radiation, oil resistance, etc. Nowadays PVC is being replaced by halogen free alternatives, mainly driven by more stringent regulations.

Material	Halogen-free	UV Resistance	Remark
LSFH Polymer	Yes	Good	Good for indoor use
Polyvinyl chloride (PVC)	No	Good	Being replaced by LSFH Polymer
Polyethylene (PE)	Yes	Poor	Good for outdoor applications
Polyurethane (PUR)	Yes	?	Highly flexible cables
Polybutylene terephthalate (PBT)	Yes	Fair?	Good for indoor use
Polyamide (PA)	Yes	Good-Poor	Indoor and outdoor use

Color coding

Patch cords

The buffer or jacket on patchcords is often color-coded to indicate the type of fiber used. The strain relief "boot" that protects the fiber from bending at a connector is color-coded to indicate the type of connection. Connectors with a plastic shell (such as SC connectors) typically use a color-coded shell. Standard color codings for jackets and boots (or connector shells) are shown below:

Buffer/jacket color	Meaning
Yellow	single-mode optical fiber
Orange	multi-mode optical fiber
Aqua	10 gig laser-optimized 50/125 micrometer multi-mode optical fiber
Grey	outdated color code for multi-mode optical fiber
Blue	Sometimes used to designate polarization-maintaining optical fiber

Connector Boot	Meaning	Comment
Blue	Physical Contact (PC), 0°	mostly used for single mode fibers; some manufacturers use this for polarization-maintaining optical fiber.
Green	Angle Polished (APC), 8°	not available for multimode fibers
Black	Physical Contact (PC), 0°	
Grey, Beige	Physical Contact (PC), 0°	multimode fiber connectors
White	Physical Contact (PC), 0°	
Red		High optical power. Sometimes used to connect external pump lasers or Raman pumps.

Remark: It is also possible that a small part of a connector is additionally colour-coded, e.g. the leaver of an E-2000 connector or a frame of an adapter. This additional colour coding indicates the correct port for a patchcord, if many patchcords are installed at one point.

Multi-fiber cables

Individual fibers in a multi-fiber cable are often distinguished from one another by color-coded jackets or buffers on each fiber. The identification scheme used by Corning Cable Systems is based on EIA/TIA-598, "**Optical Fiber Cable Color Coding**." EIA/TIA-598 defines identification schemes for fibers, buffered fibers, fiber units, and groups of fiber units within outside plant and premises optical fiber cables. This standard allows for fiber units to be identified by means of a printed legend. This method can be used for identification of fiber ribbons and fiber subunits. The legend will contain a corresponding printed numerical position number and/or color for use in identification.

EIA598-A Fiber Color Chart

Position	Jacket color
1	Blue
2	Orange
3	Green
4	Brown
5	Slate
6	White
7	Red
8	Black
9	Yellow
10	Violet
11	Rose
12	Aqua
13	Blue with black tracer
14	Orange with black tracer
15	Green with black tracer
16	Brown with black tracer
17	Slate with black tracer
18	White with black tracer
19	Red with black tracer
20	Black with yellow tracer
21	Yellow with black tracer
22	Violet with black tracer
23	Rose with black tracer
24	Aqua with black tracer

Color coding of Premise Fiber Cable

Fiber Type / Class	Diameter (µm)	Jacket Color
Multimode 1a	50/125	Orange
Multimode 1a	62.5/125	Slate
Multimode 1a	85/125	Blue
Multimode 1a	100/140	Green
Singlemode IVa	All	Yellow
Singlemode IVb	All	Red

Losses

Typical modern Multimode Graded-Index fibers have 3 dB/km of attenuation loss at 850 nm and 1dB/km at 1300 nm. 9/125 Singlemode loses 0.4/0.25 dB/km at 1310/1550 nm. POF (plastic optical fiber) loses much more: 1 dB/m at 650 nm. Plastic Optical Fiber is large core (about 1mm) fiber suitable only for short, low speed networks such as within cars.

Each connection made adds about 0.6 dB of average loss, and each joint (splice) adds about 0.1 dB. Depending on the transmitter power and the sensitivity of the receiver, if the total loss is too large the link will not function reliably.

Invisible IR light is used in commercial glass fiber communications because it has lower attenuation in such materials than visible light. However, the glass fibers will transmit visible light somewhat, which is convenient for simple testing of the fibers without requiring expensive equipment. Splices can be inspected visually, and adjusted for minimal light leakage at the joint, which maximizes light transmission between the ends of the fibers being joined.

The charts at Understanding Wavelengths In Fiber Optics and Optical power loss (attenuation) in fiber illustrate the relationship of visible light to the IR frequencies used, and show the absorption water bands between 850, 1300 and 1550 nm.

Safety

Because the infrared light used in communications can not be seen, there is a potential laser safety hazard to technicians. In some cases the power levels are high enough to damage eyes, particularly when lenses or microscopes are used to inspect fibers which are inadvertently emitting invisible IR. Inspection microscopes with optical safety filters are available to guard against this.

Small glass fragments can also be a problem if they get under someone's skin, so care is needed to ensure that fragments produced when cleaving fiber are properly picked up and disposed of.

Chapter-8

Ribbon Cable and Shielded Cable

Ribbon cable

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

A **ribbon cable** (also known as multi-wire planar cable) 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 the resemblance of the cable to a piece of ribbon.

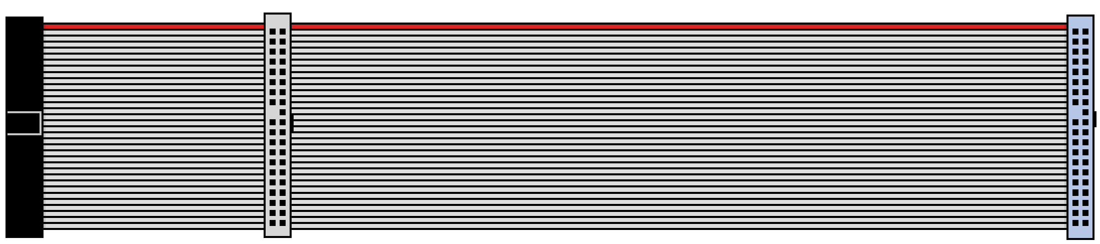
Ribbon cables are usually seen for internal peripherals in computers, such as hard drives, CD drives and floppy drives. On some older computer systems (such as the BBC Micro and Apple II series) they were used for external connections as well. Unfortunately the ribbon-like shape interferes with computer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

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 unpolarised 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.

Sizes



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).

Connectors

The main point of ribbon cables is to allow mass termination to specially designed insulation-displacement connectors (IDC) 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).
- 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.

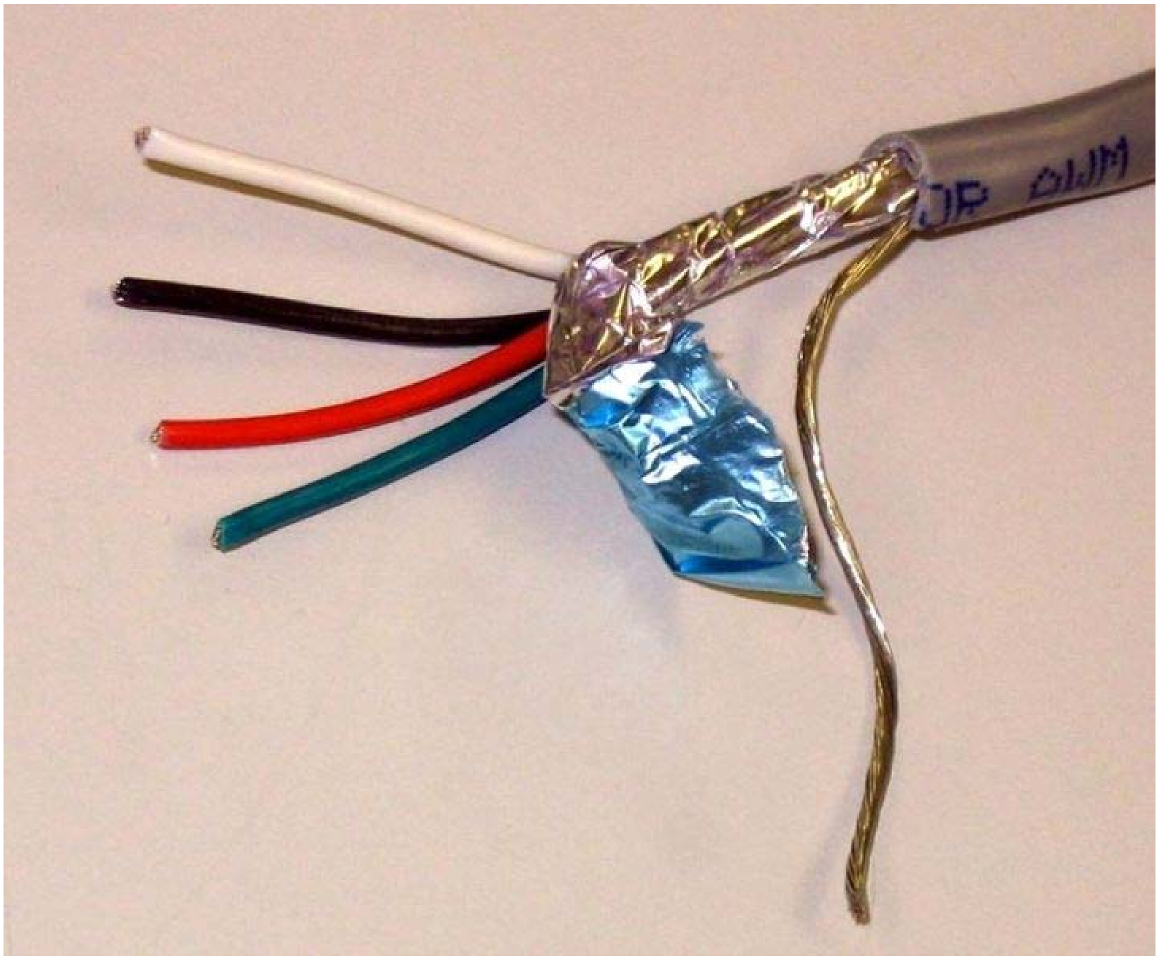
Interference

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.

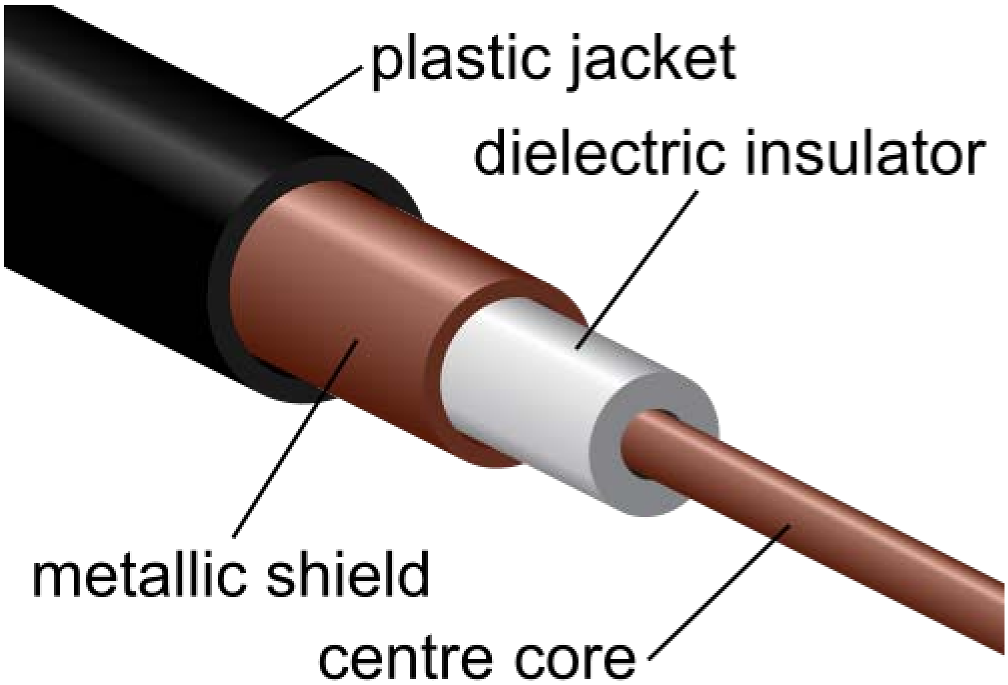
Impedance

One of the most popular sizes of ribbon cable employs 26awg size wire. Using the common 0.050" spacing and common PVC insulation the resultant impedance for any two adjacent wires within the cable is; Z = 120 (ohms). The precise number will vary a few percent due to materials. Knowledge of the impedance is one step toward undestanding and control of interference that may be caused by ribbon cables.

Shielded cable



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



Coaxial cable.

A **shielded** or **screened 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), 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. 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 and also people and equipment.

Signal cables

By twisting two conductors of a balanced-line signal circuit into a twisted pair, some cancellation of inductively coupled noise is obtained. However, a metallic shield layer over the twisted pair provides better suppression of noise. Be sure to continue the shield within control panels. Coaxial cable is used at higher frequencies to provide controlled circuit impedance, but the outer tubular conductor is also effective at reducing coupling of noise into a circuit.

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.

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. Best 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 grade microphones use screened wire with one central conductor in an unbalanced configuration.

Also see: High-end audio cables

Power cables

Medium and high-voltage power cables, in circuits over 2000 volts, usually have a shield layer of copper or aluminum 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. As well, 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. Be sure to apply stress relief/ cones at the shield ends, especially for cables operating at more than 2Kv to earth.

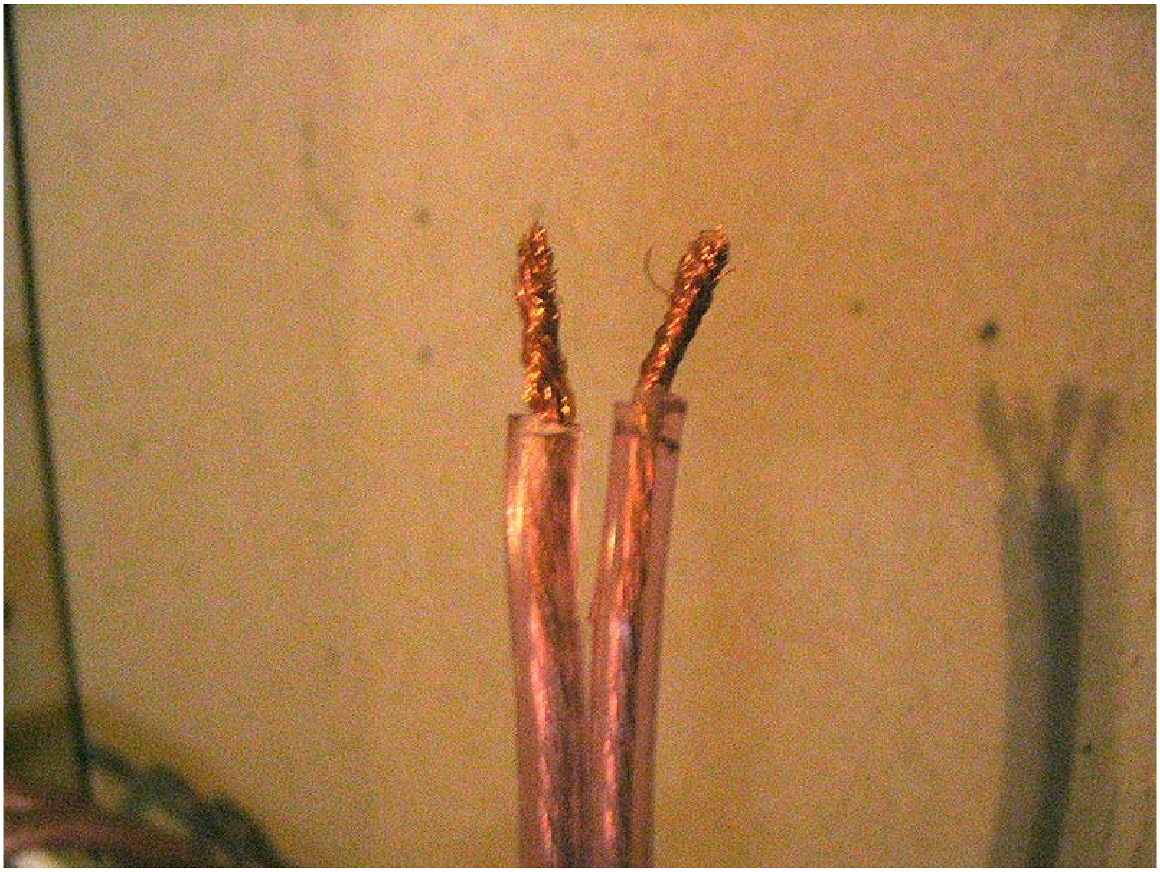
Shields on power cables are connected to earth ground at each shield end and at splices for redundancy to prevent shock even though induced current will flow in the shield. This current will produce losses and heating and will reduce the maximum current rating of the circuit. Tests show that having a bare grounding conductor adjacent to the insulated wires will conduct the fault current to earth quicker. 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. However, the shock hazard of having only one end of the shield grounded must be evaluated for the risk!

Chapter-9

Speaker Wire and Microstrip

Speaker wire

2 conductor copper speaker wire



stripped speaker wires

Speaker wire is used to make the electrical connection between loudspeakers and audio amplifiers. Modern speaker wire consists of two or more electrical conductors individually insulated by plastic such as PVC, PE or Teflon. The two wires are electrically identical, but are marked (e.g. by a ridge on the insulation of one wire, the color of one wire, a thread in one wire, etc) to help easily identify the correct polarity.

Some historic designs also featured another pair of wires for electrical power for an electromagnet in the loudspeaker. At least one such speaker design is still in production (in France), but essentially all speakers manufactured now use permanent magnets, a practice which displaced field electromagnet speakers over half a century ago.

The effect of speaker wire upon the signal it carries has been a much-debated topic in the audiophile and high fidelity worlds. The accuracy of many advertising claims on these points has also been a matter of much debate.

Explanation

Speaker wire, like any other linear electrical component, has three properties which determine its performance: resistance, capacitance, and inductance. A theoretically perfect wire has no resistance, capacitance, or inductance. The shorter a wire, the closer it comes to this, because resistance increases with the length of the conductor (except superconductors). The wire's resistance has the greatest effect on its performance. The capacitance and inductance of the wire has less effect because they are insignificant relative to the capacitance and inductance of the loudspeaker. Larger conductors (smaller wire gauge) have less resistance but increased skin effect. As long as speaker wire resistance is kept to less than 5% of the speaker's impedance, the conductor will be adequate for home use.

Speaker wires are selected based on quality of construction, price, aesthetic purpose, and convenience. Stranded wire is more flexible than solid wire, and is suitable for movable equipment. For a wire that will be exposed rather than run within walls, under floor coverings, or behind moldings (such as in a home), appearance may be a subjective benefit, but it is irrelevant to electrical characteristics. Better purification of oxidizing materials such as copper is said to result in more consistent conductive properties throughout the length of the wire, but this is a non-issue in terms of its effect on sound quality. Better jacketing may be thicker or tougher, less chemically reactive with the conductor, less likely to tangle and easier to pull through a group of other wires, or may incorporate a number of shielding techniques for non-domestic uses.

Even with poor-quality wire, an audible degradation of sound may not exist. Many supposedly audible differences in speaker wire can be attributed to listener bias or the placebo effect. Listener bias is enhanced in no small part by the popular manufacturers' practice of making claims about their products either with no valid engineering or scientific basis, or of no real-world significance. Many manufacturers catering to audiophiles (as well as those supplying less expensive retail markets) also make unmeasurable, if poetic, claims about their wire sounding open, dynamic, or smooth. To justify these claims, many cite electrical properties such as skin effect, characteristic impedance of the cable, or resonance, which are generally little understood by consumers. None of these has any measurable effect at audio frequencies, though each matters at radio frequencies.

Resistance

Resistance is by far the most important specification of speaker wire. Low-resistance speaker wire allows more of the amplifier's power to energize the loudspeaker's voice coil. The shorter the cable and the greater the conductor's cross-sectional area, the lower its resistance. Depending on the hearing ability of the listener, this resistance begins to have an audible effect when the resistance exceeds 5% of the speaker's impedance.

A speaker wire’s impedance takes into account the wire’s resistance, the wire’s path (coiled wire acts as an inductor), and the dielectric properties of local insulators. The latter two factors also determine the wire's frequency response. The lower the impedance of the speaker, the greater a significance the speaker wire's resistance will have.

Wire gauge

Thicker wires reduce resistance. The resistance of 16-gauge or heavier speaker connection cable has no detectable effect in runs of 50 feet (15 meters) or less in standard domestic loudspeaker connections for a typical 8 ohm speaker. As speaker resistance drops, lower gauge (heavier) wire is needed to prevent degradation to damping factor—a measure of the amplifier's control over the position of the voice coil.

Insulation thickness or type also has no audible effect as long as the insulation is of good quality and does not chemically react with the wire itself (poor-quality insulation has occasionally been found to accelerate oxidation of the copper conductor, increasing resistance over time). High-power in-car audio systems using 2-ohm speaker circuits require thicker wire than 4 to 8-ohm home audio applications.

Most consumer applications use two conductor wire. Based on a guideline is that the resistance of the speaker wire not exceeding 5% of the rated impedance of the system the table below illustrates recommended lengths.

Maximum wire lengths for two conductor copper wire

Wire size	2 Ω load	4 Ω load	6 Ω load	8 Ω load
22 AWG (0.326 mm^2)	3 ft (0.9 m)	6 ft (1.8 m)	9 ft (2.7 m)	12 ft (3.6 m)
20 AWG (0.518 mm^2)	5 ft (1.5 m)	10 ft (3 m)	15 ft (4.5 m)	20 ft (6 m)
18 AWG (0.823 mm^2)	8 ft (2.4 m)	16 ft (4.9 m)	24 ft (7.3 m)	32 ft (9.7 m)
16 AWG (1.31 mm^2)	12 ft (3.6 m)	24 ft (7.3 m)	36 ft (11 m)	48 ft (15 m)
14 AWG (2.08 mm^2)	20 ft (6.1 m)	40 ft (12 m)	60 ft (18 m)*	80 ft (24 m)*
12 AWG (3.31 mm^2)	30 ft (9.1 m)	60 ft (18 m)*	90 ft (27 m)*	120 ft (36 m)*
10 AWG (5.26 mm^2)	50 ft (15 m)	100 ft (30 m)*	150 ft (46 m)*	200 ft (61 m)*

* While in theory heavier wire can have longer runs, recommended household audio lengths should not exceed 50 feet (15 m).

The gauge numbers in SWG (standard wire gauge) and AWG (American wire gauge) reduce as the wire gets larger. Sizing in square millimeters is also common.

Wire material

Use of copper is more or less universal for speaker wire; it has low resistance and less cost compared to other suitable materials. Copper and aluminum both oxidize, but oxides of copper are conductive, while those of aluminum are insulating.

Silver has a slightly lower resistivity than copper, which allows a thinner wire to have the same resistance. Silver is expensive, so a copper wire with the same resistance costs considerably less. Silver tarnishes to form a thin surface layer of silver sulfide.

Gold has a higher resistivity than either copper or silver, but it does not oxidize, so it can be used for wire-end terminations. Suitably specified gold flashing has its uses for appropriate tasks, but in domestic use such flashing is not normally functional, for several reasons.

Capacitance and inductance

Speaker wire capacitance and inductance normally have no effect on audio quality, though extreme examples using unusually low-impedance speakers and exceptionally long wire runs can show a small effect.

Terminations

Speaker wire terminations are optional and largely for convenience. Bare wire ends work just as well electrically, and may work better mechanically as adding a termination introduces another potential point of error in installation or failure over time. The most common termination types are solder-tinned wire ends, soldered or crimped pin or spade lugs, banana plugs, and 2-pin DIN connectors. Which type to use is determined by the connectors on the equipment at each end of the wire.

Some terminations are gold plated, which is of no functional use on consumer equipment speaker lines, except to help market equipment to end users unfamiliar with the relevant principles. In a moist environment, gold-plated connectors can resist corrosion better than some other materials, although they should only be mated with other gold-plated connectors as galvanic corrosion may otherwise occur.

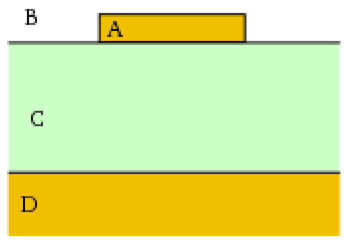
Many speakers and electronics have flexible five-way binding posts that can be screwed down or held down by a spring to accept bare or soldered wire and pins or springy banana plugs (through a hole in the outward-facing side of the post).

There are also several types of proprietary connectors, though these are largely on all-in-one entertainment centers and bookshelf stereo systems.

In recent years, the Neutrik speakON connector is appearing more and more on professional audio equipment. One reason is simple: in many European countries the banana plug can fit into 230 V main electrical sockets. A mistake will damage equipment, and could possibly injure or kill someone as well. Recent EU regulations prohibit banana plugs in non-AC equipment, unless equipped with a safety pin mechanism preventing insertion into a wall outlet; there is such a connector available (from WBT Connectors), but it is not widely used.

Additionally, the Neutrik speakON connector twists to lock in place, preventing one cause of intermittent failure, and accidental disconnection common in well-used banana plug connections. The speakON also carries more current than heavy-duty 15 A 0.25 in (6.4 mm) phone plugs (originally used in the telephone industry), and does not short two conductors together at insertion/removal.

Microstrip



Cross-section of microstrip geometry. Conductor (A) is separated from ground plane (D) by dielectric substrate (C). Upper dielectric (B) is typically air.

Microstrip is a type of electrical transmission line which can be fabricated using printed circuit board [PCB] technology, and is used to convey microwave-frequency signals. It consists of a conducting strip separated from a ground plane by a dielectric layer known as the **substrate**. Microwave components such as antennas, couplers, filters, power dividers etc. can be formed from microstrip, the entire device existing as the pattern of metallization on the substrate. Microstrip is thus much less expensive than traditional waveguide technology, as well as being far lighter and more compact.

The disadvantages of microstrip compared with waveguide are the generally lower power handling capacity, and higher losses. Also, unlike waveguide, microstrip is not enclosed, and is therefore susceptible to cross-talk and unintentional radiation.

For lowest cost, microstrip devices may be built on an ordinary FR-4 (standard PCB) substrate. However it is often found that the dielectric losses in FR4 are too high at microwave frequencies, and that the dielectric constant is not sufficiently tightly controlled. For these reasons, an alumina substrate is commonly used.

On a smaller scale, microstrip transmission lines are also built into monolithic microwave integrated circuits [MMIC]s.

Microstrip lines are also used in high-speed digital PCB designs, where signals need to be routed from one part of the assembly to another with minimal distortion, and avoiding high cross-talk and radiation.

Microstrip is very similar to stripline and coplanar waveguide [CPW], and it is possible to integrate all three on the same substrate.

Inhomogeneity

The electromagnetic wave carried by a microstrip line exists partly in the dielectric substrate, and partly in the air above it. In general, the dielectric constant of the substrate will be different (and greater) than that of the air, so that the wave is travelling in an inhomogeneous medium. In consequence, the propagation velocity is somewhere between the speed of radio waves in the substrate, and the speed of radio waves in air. This behaviour is commonly described by stating the **effective dielectric constant** (or **effective relative permittivity**) of the microstrip; this being the dielectric constant of an equivalent homogeneous medium (i.e. one resulting in the same propagation velocity).

Further consequences of an inhomogeneous medium include:

- The line will not support a true TEM wave; at non-zero frequencies, both the E and H fields will have longitudinal components (a hybrid mode). The longitudinal components are small however, and so the dominant mode is referred to as **quasi-TEM**.

- The line is dispersive. With increasing frequency, the effective dielectric constant gradually climbs towards that of the substrate, so that the phase velocity gradually decreases. This is true even with a non-dispersive substrate material (the substrate dielectric constant will usually fall with increasing frequency).

- The characteristic impedance of the line changes slightly with frequency (again, even with a non-dispersive substrate material). The characteristic impedance of non-TEM modes is not uniquely defined, and depending on the precise definition used, the impedance of microstrip either rises, falls, or falls then rises with increasing frequency. The low-frequency limit of the characteristic impedance is referred to as the **quasi-static characteristic impedance**, and is the same for all definitions of characteristic impedance.

- The wave impedance varies over the cross-section of the line.

Characteristic Impedance

A closed-form approximate expression for the quasi-static characteristic impedance of a microstrip line was developed by Wheeler:

$$Z_{\text{microstrip}} = \frac{Z_0}{2\pi\sqrt{2(1+\varepsilon_r)}} \ln\left(1 + \frac{4h}{w_{\text{eff}}}\left(\frac{14+\frac{8}{\varepsilon_r}}{11}\frac{4h}{w_{\text{eff}}} + \sqrt{\left(\frac{14+\frac{8}{\varepsilon_r}}{11}\frac{4h}{w_{\text{eff}}}\right)^2 + \pi^2\frac{1+\frac{1}{\varepsilon_r}}{2}}\right)\right)$$

where w_{eff} is the *effective width*, which is the actual width of the strip, plus a correction to account for the non-zero thickness of the metallization. The effective width is given by

$$w_{\text{eff}} = w + t\frac{1+\frac{1}{\varepsilon_r}}{2\pi}\ln\left(\frac{4e}{\sqrt{\left(\frac{t}{h}\right)^2 + \left(\frac{1}{\pi}\frac{1}{\frac{w}{t}+\frac{11}{10}}\right)^2}}\right)$$

with

> Z_0 = impedance of free space,
> $\varepsilon_r =$ dielectric constant of substrate,
> w = width of strip,
> h = thickness ('height') of substrate and
> t = thickness of strip metallization.

This formula is asymptotic to an exact solution in three different cases

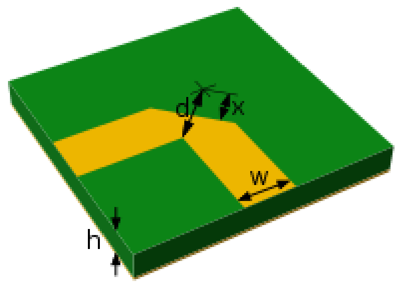
1. $w \gg h$, any ε_r (parallel plate transmission line),
2. $w \ll h, \varepsilon_r = 1$ (wire above a ground-plane) and
3. $w \ll h, \varepsilon_r \gg 1$.

It is claimed that for most other cases, the error in impedance is less than 1%, and is always less than 2%. By covering all aspect-ratios in one formula, Wheeler 1977 improves on Wheeler 1965 which gives one formula for $w / h > 3.3$ and another for $w/h \leq 3.3$ (thus introducing a discontinuity in the result at $w / h = 3.3$). Nevertheless, the 1965 paper is perhaps the more often cited. A number of other approximate formulae for the characteristic impedance have been advanced by other authors. However, most of these are applicable to only a limited range of aspect-ratios, or else cover the entire range piecewise.

Curiously, Harold Wheeler disliked both the terms 'microstrip' and 'characteristic impedance', and avoided using them in his papers.

Bends

In order to build a complete circuit in microstrip, it is often necessary for the path of a strip to turn through a large angle. An abrupt 90° bend in a microstrip will cause a significant portion of the signal on the strip to be reflected back towards its source, with only part of the signal transmitted on around the bend. One means of effecting a low-reflection bend, is to curve the path of the strip in an arc of radius at least 3 times the strip-width. However, a far more common technique, and one which consumes a smaller area of substrate, is to use a **mitred bend**.



Microstrip 90° mitred bend. The percentage mitre is 100x/d

To a first approximation, an abrupt un-mitred bend behaves as a shunt capacitance placed between the ground plane and the bend in the strip. Mitring the bend reduces the area of metallization, and so removes the excess capacitance. The **percentage mitre** is the cut-away fraction of the diagonal between the inner and outer corners of the un-mitred bend.

The optimum mitre for a wide range of microstrip geometries has been determined experimentally by Douville and James. They find that a good fit for the optimum percentage mitre is given by,

$$M = 100\frac{x}{d}\% = (52 + 65e^{-\frac{27}{20}\frac{w}{h}})\%$$

subject to $w/h \geq 0.25$and the with the substrate dielectric constant $\varepsilon_r \leq 25$. This formula is entirely independent of ε_r. The actual range of parameters for which Douville and James present evidence is $0.25 \leq w/h \leq 2.75$and $2.5 \leq \varepsilon_r \leq 25$. They report a VSWR of better than 1.1 (i.e. a return better than -26dB) for any percentage mitre within 4% (of the original *d*) of that given by the formula. Note that for the minimum *w* / *h* of 0.25, the percentage mitre is 96%, so that the strip is very nearly cut through.

For both the curved and mitred bends, the electrical length is somewhat shorter than the physical path-length of the strip.

Chapter-10

Copper Cable Certification and Twinaxial Cabling

Copper cable certification

10G Certification Kit

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. These tests are done using a certification-testing tool, which provide “Pass” or “Fail” information. While certification can be performed by the owner of the network, certification is primarily done by datacom contractors. It is this certification that allows the contractors to warranty their work.

Need for certification

Installers who need to prove to the network owner that the installation has been done correctly and meets TIA or ISO standards need to certify. Network owners who want to guarantee that the infrastructure is capable of handling a certain application (e.g. Voice over Internet) will use a tester to certify the network infrastructure. In some cases, these testers are used to pinpoint specific problems. Certification tests are vital if there is a discrepancy between the installer and network owner after an installation has been performed.

The Standards

The performance tests and their procedures have been defined in the ANSI/TIA/EIA-568-B.1 standard and the ISO/IEC 11801 standard. The TIA standard defines performance in categories (Cat 3, Cat 5e, Cat 6) and the ISO defines classes (Class C, D, E, and F). These standards define the procedure to certify that an installation meets performance criteria in a given category or class.

The significance of each category or class is the limit values of which the Pass/Fail and frequency ranges are measured; Cat 3 and Class C (no longer used) test and define communication with 16 MHz bandwidth, Cat 5e and Class D with 100 MHz bandwidth, Cat 6 and Class E up to 250 MHz, and Cat 7 and Class F with a frequency range through 600 MHz.

The standards also define that data from each test result must be collected and stored in either print or electronic format for future inspection.

The Tests

Test Parameter	TIA-568-B	ISO 11801:2002
Wiremap	Pass/Fail	Pass/Fail
Propagation Delay	Pass/Fail	Pass/Fail
Delay Skew	Pass/Fail	Pass/Fail
Cable Length	Pass/Fail	Information only
Insertion Loss (IL)	Pass/Fail	Pass/Fail
Return Loss (RL)	Pass/Fail (except Cat3)	Pass/Fail
Near-End Crosstalk (NEXT)	Pass/Fail	Pass/Fail
Power Sum NEXT (PSNEXT)	Pass/Fail	Pass/Fail

Equal-Level Far-End Crosstalk (ELFEXT)	Pass/Fail	Pass/Fail
Power Sum ELFEXT (PSELFEXT)	Pass/Fail	Pass/Fail
Attenuation-to-Crosstalk Ratio (ACR)	Information only	Pass/Fail (except Class C)
Power sum ACR (PSACR)	Information only	Pass/Fail (except Class C)
DC Loop Resistance		Pass/Fail

Wiremap

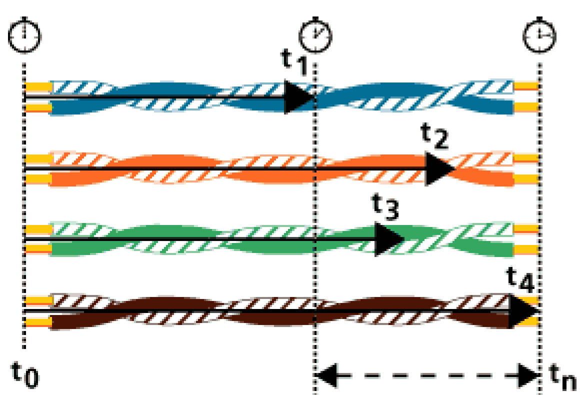
The Wiremap test is used to identify physical errors of the installation; proper pin termination at each end, shorts between any two or more wires, continuity to the remote end, split pairs, crossed pairs, reversed pairs, and any other mis-wiring.

Propagation Delay

The Propagation Delay test tests for the time it takes for the signal to be sent from one end and received by the other end.

Delay Skew

The Delay Skew test tests for the difference in propagation delay between the fastest and slowest set of wire pairs. An ideal skew is between 25 and 50 nanoseconds over a 100 meter cable. The lower this skew the better, less than 25 ns is excellent, but 45 to 50 ns is marginal.



Cable Length

The Cable Length test verifies that the cable from the transmitter to receiver does not exceed the maximum recommended distance of 100 meters in a 10BASE-T/100BASE-TX/1000BASE-T network.

Insertion Loss

Insertion loss, also referred to as attenuation, refers to the loss of signal strength at the far end of a line compared to the signal that was introduced into the line. This loss is due to the electrical resistance of the copper cable, the loss of energy through the cable insulation and the impedance caused by the connectors. Insertion loss is usually expressed in decibels dB with a minus sign. Insertion loss increases with distance and frequency. For every 6dB of loss, the original signal will be half the original amplitude.

Decibels vs. Voltage

dB	Voltage Ratio	dB	Voltage Ratio	dB	Voltage Ratio	dB	Voltage Ratio
0	1V	-13	.224	-6	.500	-19	.112
-1	.891	-14	.200	-7	.447	-20	.100
-2	.794	-15	.178	-8	.398	-30	.032
-3	.707	-16	.158	-9	.355	-40	.010
-4	.631	-17	.141	-10	.316	-50	.003
-5	.562	-18	.125	-11	.282	-60	.001
				-12	.250	-80	.000

Return Loss

Return Loss is the measurement (in dB) of the amount of signal that is reflected back toward the transmitter. The reflection of the signal is caused by the variations of impedance in the connectors and cable and is usually attributed to a poorly terminated wire. The greater the variation in impedance, the greater the return loss reading. If 3 pairs of wire pass by a substantial amount, but the 4 pair barely passes, it usually is an indication of a bad crimp or bad connection at the RJ45 plug. Return loss is usually not significant in the loss of a signal, but rather signal jitter.

Near-End Crosstalk (NEXT)

Near-End Crosstalk (NEXT) is an error condition that describes the occurrence of a signal from one wire pair radiating to and interfering with the signal of another wire pair. It is the difference in amplitude (in dB) between a transmitted signal and the crosstalk received on other cable pairs at the same end of the cabling. Higher NEXT values correspond to better cabling performance. A higher value is desirable as it would indicate that the power transmitted is greater in magnitude than the power induced onto another wire pair given that the NEXT measurement is simply a difference calculation. NEXT must be measured from each pair to each other pair in twisted pair cabling and from each end of the connection. NEXT is measured 30 meters (about 98 feet) from the injector / generator. Lower near end crosstalk values correspond to higher overall circuit performance. High NEXT values on a UTP LAN that will be using an older signaling standard (IEEE 802.3i and earlier) are particularly detrimental. It could be an indication of improper termination.

Power Sum NEXT (PSNEXT)

Power Sum NEXT (PSNEXT) is the sum of NEXT values from 3 wire pairs as they affect the other wire pair. The combined effect of NEXT can be very detrimental to the signal.

The Equal-Level Far-End Crosstalk (ELFEXT)

The Equal-Level Far-End Crosstalk (ELFEXT) test measures Far-End Crosstalk (FEXT). FEXT is very similar to NEXT, but happens at the receiver side of the connection. Due to impedance on the line, crosstalk diminishes the signal as it gets further away from the transmitter. Because of this, FEXT is usually less detrimental to a signal than NEXT, but still important nonetheless.

Power Sum ELFEXT (PSELFEXT)

Power Sum ELFEXT (PSELFEXT) is the sum of FEXT values from 3 wire pairs as they affect the other wire pair.

Attenuation-to-Crosstalk ratio (ACR)

Attenuation-to-Crosstalk ratio (ACR) is the difference between the signal attenuation produced and NEXT and is measured in decibels (dB). The ACR indicates how much stronger the attenuated signal is than the crosstalk at the destination (receiving) end of a communications circuit. The ACR figure must be at least several decibels for proper performance. If the ACR is not large enough, errors will be frequent. In many cases, even a small improvement in ACR can cause a dramatic reduction in the bit error rate. Sometimes it may be necessary to switch from un-shielded twisted pair (UTP) cable to shielded twisted pair (STP) in order to increase the ACR.

Power Sum ACR (PSACR)

Power Sum ACR (PSACR) done in the same way as ACR, but using the PSNEXT value in the calculation rather than NEXT.

DC Loop Resistance

DC Loop Resistance measures the total resistance through one wire pair looped at one end of the connection. This will increase with the length of the cable. DC resistance usually has less effect on a signal than insertion loss, but plays a major role if power over Ethernet is required. Also measured in ohms is the characteristic impedance of the cable, which is independent of the cable length.

Twinaxial cabling

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

Legacy applications

IBM

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

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

Straight Twinax cables can go up to 5,000 feet (1,500 m). 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 as a replacement for RS-232 dumb terminals. 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. 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 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).

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.

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.

NEC

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

MIL-STD-1553

Although MIL-STD-1553 specifies that the data bus should have characteristic impedance between 70 and 85 ohms, 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.

Current applications

SFP+ Direct Attach (10GSFP+Cu)

This is a copper 10 Gigabit Ethernet cable that comes in either an active or passive twin-ax cable assembly and connects directly into an SFP+ housing. The active twin-ax cable has active electronic components in the SFP+ housing to improve the signal quality; the passive twin-ax cable is just a straight "wire" and contain no active components. Generally twin-ax cables that are 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 is expected to be the optimum solution for reaches of 10 m.

One of major applications includes Cisco Systems implementation coupled with SFP+ modules. This type of connection is able to transmit at 10 Gigabit full duplex speed over 5 meter distances. Moreover this setup offers 15 to 25 times lower transceiver latency than current 10GBASE-T CAT6/CAT6a/CAT7 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.

DisplayPort

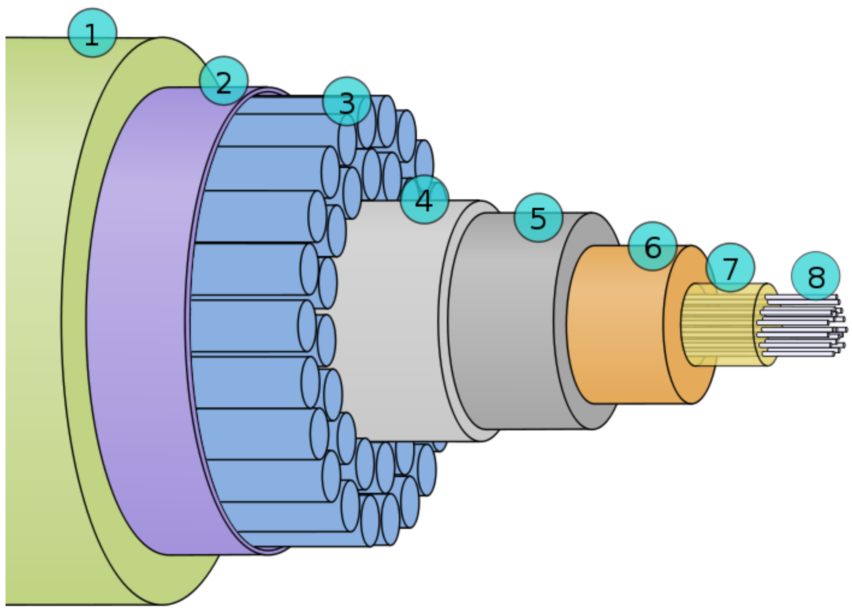
Many manufacturers of DisplayPort cabling are also using twinaxial configurations to accommodate the strict insertion loss, return loss, and crosstalk requirements for the 2.7 Gbit/s signaling rate.

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.

Chapter-11

Submarine Communications Cable



A cross section of a submarine communications cable.
1 - Polyethylene
2 - Mylar tape
3 - Stranded steel wires
4 - Aluminium water barrier
5 - Polycarbonate
6 - Copper or aluminium tube
7 - Petroleum jelly
8 - Optical fibers

Submarine cables are laid using special cable layer ships, such as the modern *René Descartes*, operated by France Telecom Marine.

A **submarine communications cable** is a cable laid beneath the sea to carry telecommunications under stretches of water.

The first submarine communications cables carried telegraphy traffic. Subsequent generations of cables carried first telephony traffic, then data communications traffic. All modern cables use optical fiber technology to carry digital payloads, which are then used to carry telephone traffic as well as Internet and private data traffic. They are typically 69 millimetres (2.7 in) in diameter and weigh around 10 kilograms per metre (7 lb/ft), although thinner and lighter cables are used for deep-water sections.

As of 2010, submarine cables link all the world's continents except Antarctica.

Early history: telegraph and coaxial cables

Trials

After William Cooke and Charles Wheatstone had introduced their working telegraph in 1839, the idea of a submarine line across the Atlantic Ocean began to be thought of as a possible triumph of the future. Samuel Morse proclaimed his faith in it as early as the year 1840, and in 1842 he submerged a wire, insulated with tarred hemp and India rubber, in the water of New York Harbor, and telegraphed through it. The following autumn Wheatstone performed a similar experiment in Swansea Bay. A good insulator to cover the wire and prevent the electric current from leaking into the water was necessary for the success of a long submarine line. India rubber had been tried by Moritz von Jacobi, the Prussian electrical engineer, as far back as the early 19th century.

Another insulating gum which could be melted by heat and readily applied to wire made its appearance in 1842. Gutta-percha, the adhesive juice of the *Palaquium gutta* tree, was introduced to Europe by William Montgomerie, a Scottish surgeon in the service of the British East India Company. Twenty years earlier he had seen whips made of it in Singapore, and he believed that it would be useful in the fabrication of surgical apparatuses. Michael Faraday and Wheatstone soon discovered the merits of gutta-percha as an insulator, and in 1845 the latter suggested that it should be employed to cover the wire which was proposed to be laid from Dover to Calais. It was tried on a wire laid across the Rhine between Deutz and Cologne. In 1849 C.V. Walker, electrician to the South Eastern Railway, submerged a wire coated with gutta percha along the coast off Dover.

The first commercial cables

In August 1850, John Watkins Brett's Anglo-French Telegraph Company laid the first line across the English Channel. It was simply a copper wire coated with gutta-percha, without any other protection. The experiment served to keep alive the concession, and the next year, on November 13, 1851, a protected core, or true cable, was laid from a government hulk, the *Blazer*, which was towed across the Channel. The next year, Great Britain and Ireland were linked together. In 1852, a cable laid by the Submarine Telegraph Company linked London to Paris for the first time. In May, 1853, England was joined to the Netherlands by a cable across the North Sea, from Orford Ness to The Hague. It was laid by the *Monarch*, a paddle steamer which had been fitted for the work.

Transatlantic telegraph cable

The first attempt at laying a transatlantic telegraph cable was promoted by Cyrus West Field, who persuaded British industrialists to fund and lay one in 1858. However, the technology of the day was not capable of supporting the project; it was plagued with problems from the outset, and was in operation for only a month. Subsequent attempts in 1865 and 1866 with the world's largest steamship, the SS *Great Eastern*, used a more advanced technology and produced the first successful transatlantic cable. The *Great Eastern* later went on to lay the first cable reaching to India from Aden, Yemen, in 1870.

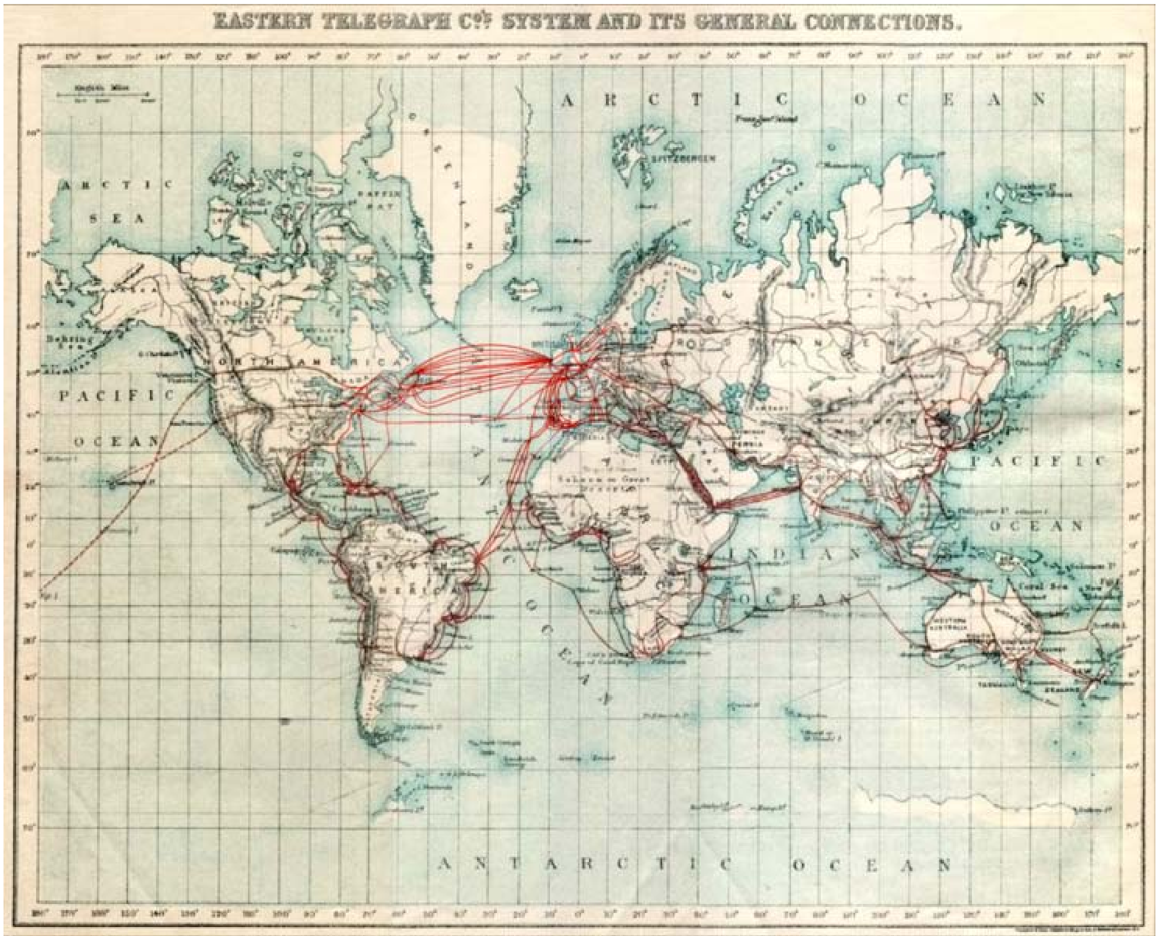
British dominance of early cable

From the 1850s until 1911, British submarine cable systems dominated the most important market, the North Atlantic Ocean. The British had both supply side and demand side advantages. In terms of supply, Britain had entrepreneurs willing to put forth enormous amounts of capital necessary to build, lay and maintain these cables. In terms of demand, the vast colonial empire Britain held led to business for the cable companies from news agencies, trading and shipping companies, and the British government. Many of Britain's colonies had significant populations of European settlers, making news about them of interest to the general public in the home country.

The submarine cables were an economic boon to trade companies because owners of ships could communicate with captains when they reached their destination on the other side of the ocean and even give directions as to where to go next to pick up more cargo based on reported pricing and supply information. The British government had obvious uses for the cables in maintaining administrative communications with governors throughout its empire as well as in engaging other nations diplomatically and communicating with its military units in wartime. Location of Britain's territory was also an advantage as it possessed both Ireland and Newfoundland, making for the shortest route across the Atlantic Ocean (reducing cost significantly).

A few facts put this dominance of the industry in perspective. In 1896, there were thirty cable laying ships in the world and twenty-four of them were owned by British companies. In 1892, British companies owned and operated two-thirds of the world's cables and by 1923 their share was still 42.7 percent.

Cable to India, Singapore, Far East and Australasia



Eastern Telegraph Company network in 1901

An 1863 cable to Mumbai, India (then known in the English-speaking world as Bombay) provided a crucial link to Saudi Arabia. In 1870 Bombay was linked to London via submarine cable in a combined operation by four cable companies, at the behest of the British Government. In 1872 these four companies were combined to form the mammoth globespanning Eastern Telegraph Company, owned by John Pender. A spin-off from Eastern Telegraph Company was a second sister company, the Eastern Extension, China and Australasia Telegraph Company, commonly known simply as "the Extension". In 1872, Australia was linked by cable to Bombay via Singapore and China and in 1876 the cable linked the British Empire from London to New Zealand.

Submarine cable across the Pacific

This was completed in 1902–03, linking the US mainland to Hawaii in 1902 and Guam to the Philippines in 1903. Canada, Australia, New Zealand and Fiji were also linked in 1902.

Decades later, the North Pacific Cable system was the first regenerative (repeatered) system to completely cross the Pacific from the US mainland to Japan. The US portion of NPC was manufactured in Portland, Oregon, from 1989–1991 at STC Submarine Systems, and later Alcatel Submarine Networks. The system was laid by Cable & Wireless Marine on the *CS Cable Venture* in 1991.

Construction

Transatlantic cables of the 19th century consisted of an outer layer of iron and later steel wire, wrapping India rubber, wrapping gutta-percha, which surrounded a multi-stranded copper wire at the core. The portions closest to each shore landing had additional protective armor wires. Gutta-percha, a natural polymer similar to rubber, had nearly ideal properties for insulating submarine cables, with the exception of a rather high dielectric constant which made cable capacitance high. Gutta-percha was not replaced as a cable insulation until polyethylene was introduced in the 1930s. In the 1920s, the American military experimented with rubber-insulated cables as an alternative to gutta-percha, since American interests controlled significant supplies of rubber but no gutta-percha manufacturers.

Bandwidth problems

Early long-distance submarine telegraph cables exhibited formidable electrical problems. Unlike modern cables, the technology of the 19th century did not allow for in-line repeater amplifiers in the cable. Large voltages were used to attempt to overcome the electrical resistance of their tremendous length but the cables' distributed capacitance and inductance combined to distort the telegraph pulses in the line, severely limiting the data rate for telegraph operation. Thus, the cables had very limited bandwidth.

As early as 1823, Francis Ronalds had observed that electric signals were retarded in passing through an insulated wire or core laid underground, and the same effect was noticed by Latimer Clark (1853) on cores immersed in water, and particularly on the lengthy cable between England and The Hague. Michael Faraday showed that the effect was caused by capacitance between the wire and the earth (or water) surrounding it. Faraday had noted that when a wire is charged from a battery (for example when pressing a telegraph key), the electric charge in the wire induces an opposite charge in the water as it travels along. In 1831, Faraday described this effect in what is now referred to as Faraday's law of induction; this discovery proved to be an essential influence on the work of future physicists such as James Clerk Maxwell (whose work went on to define classical electrodynamics, most notably through what are known today as Maxwell's Equations), Albert Einstein (in the formulation of special relativity), and Richard Feynman. As the two charges attract each other, the exciting charge is retarded. The core acts as a capacitor distributed along the length of the cable which, coupled with the resistance and inductance of the cable limits the speed at which a signal travels through the conductor of the cable.

Early cable designs failed to analyze these effects correctly. Famously, E.O.W. Whitehouse had dismissed the problems and insisted that a transatlantic cable was feasible. When he subsequently became electrician of the Atlantic Telegraph Company he became involved in a public dispute with William Thomson. Whitehouse believed that, with enough voltage, any cable could be driven. Because of the excessive voltages recommended by Whitehouse, Cyrus West Field's first transatlantic cable never worked reliably, and eventually short circuited to the ocean when Whitehouse increased the voltage beyond the cable design limit.

Thomson designed a complex electric-field generator that minimized current by resonating the cable, and a sensitive light-beam mirror galvanometer for detecting the faint telegraph signals. Thomson became wealthy on the royalties of these, and several related inventions. Thomson was elevated to Lord Kelvin for his contributions in this area, chiefly an accurate mathematical model of the cable, which permitted design of the equipment for accurate telegraphy. The effects of atmospheric electricity and the geomagnetic field on submarine cables also motivated many of the early polar expeditions.

Thomson had produced a mathematical analysis of propagation of electrical signals into telegraph cables based on their capacitance and resistance, but since long submarine cables operated at slow rates, he did not include the effects of inductance. By the 1890s, Oliver Heaviside had produced the modern general form of the telegrapher's equations which included the effects of inductance and which were essential to extending the theory of transmission lines to higher frequencies required for high-speed data and voice.

Transatlantic telephony

Five submarine communication cables crossing the Scottish shore at Scad Head on Hoy, Orkney.

While laying a transatlantic telephone cable was seriously considered from the 1920s, a number of technological advances were required for cost-efficient telecommunications that did not arrive until the 1940s. A first attempt to lay a pupinized telephone cable failed in the early 1930s due to the Great Depression.

In 1942, Siemens Brothers of New Charlton, London in conjunction with the United Kingdom National Physical Laboratory, adapted submarine communications cable technology to create the world's first submarine oil pipeline in Operation Pluto during World War II.

TAT-1 (Transatlantic No. 1) was the first transatlantic telephone cable system. Between 1955 and 1956, cable was laid between Gallanach Bay, near Oban, Scotland and Clarenville, Newfoundland and Labrador. It was inaugurated on September 25, 1956, initially carrying 36 telephone channels.

In the 1960s, transoceanic cables were coaxial cables that transmitted frequency-multiplexed voiceband signals. A high voltage direct current on the inner conductor powered the repeaters. The first-generation repeaters are among the most reliable vacuum tube amplifiers ever designed. Later ones were transistorized. Many of these cables are still usable, but abandoned because their capacity is too small to be commercially viable. Some have been used as scientific instruments to measure earthquake waves and other geomagnetic events.

Modern history

Optical telephone cables

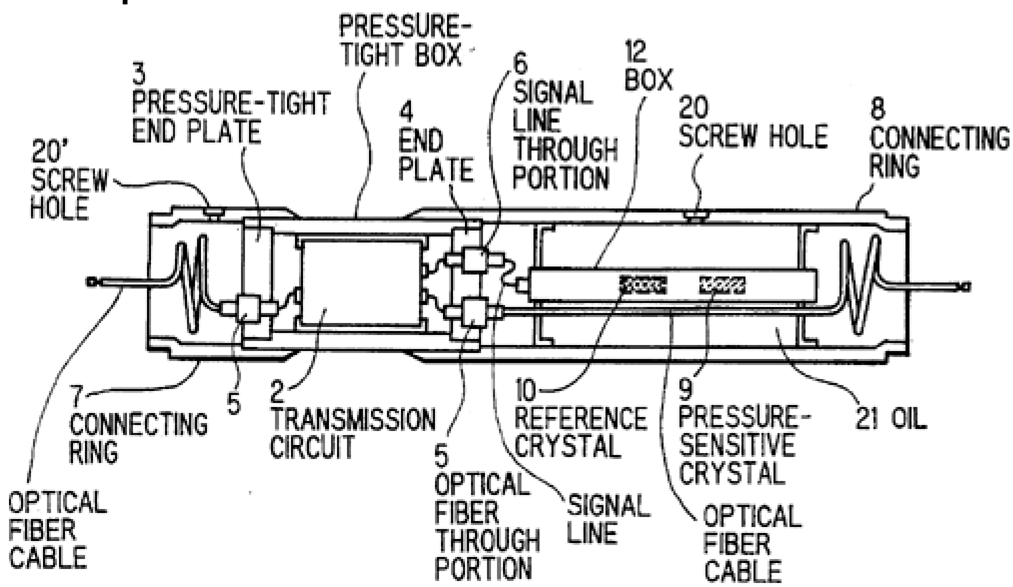


Diagram of an optical submarine cable repeater.

In the 1980s, fiber optic cables were developed. The first transatlantic telephone cable to use optical fiber was TAT-8, which went into operation in 1988. A fiber-optic cable comprises multiple pairs of fibers. Each pair has one fiber in each direction. TAT-8 had two operational pairs and one backup pair.

Modern optical fiber repeaters use a solid-state optical amplifier, usually an Erbium-doped fiber amplifier. Each repeater contains separate equipment for each fiber. These comprise signal reforming, error measurement and controls. A solid-state laser dispatches the signal into the next length of fiber. The solid-state laser excites a short length of doped fiber that itself acts as a laser amplifier. As the light passes through the fiber, it is amplified. This system also permits wavelength-division multiplexing, which dramatically increases the capacity of the fiber.

Repeaters are powered by a constant direct current passed down the conductor near the center of the cable, so all repeaters in a cable are in series. Power feed equipment is installed at the terminal stations. Typically both ends share the current generation with one end providing a positive voltage and the other a negative voltage. A virtual earth point exists roughly half way along the cable under normal operation. The amplifiers or repeaters derive their power from the potential difference drop across them.

The optic fiber used in undersea cables is chosen for its exceptional clarity, permitting runs of more than 100 kilometers between repeaters to minimize the number of amplifiers and the distortion they cause.

The rising demand for these fiber-optic cables outpaced providers', such as AT&T, capacity. Having to shift traffic to satellites resulted in poorer quality signals. To address this issue, AT&T had to improve its cable laying abilities. It invested $100 million in producing two specialized fiber-optic cable laying vessels. These included laboratories in the ships for splicing cable together and testing its electrical properties. Such field monitoring is important because the glass of fiber-optic cable is less malleable than the previous copper cable that had been used. The ships are further equipped with special additional propellers that increase maneuverability. This capability is important because fiber-optic cable must be laid out straight from the stern (another factor copper cable laying ships did not have to contend with).

Originally, submarine cables were simple point-to-point connections. With the development of submarine branching units (SBUs), more than one destination could be served by a single *cable system*. Modern cable systems now usually have their fibers arranged in a self-healing ring to increase their redundancy, with the submarine sections following different paths on the ocean floor. One driver for this development was that the capacity of cable systems had become so large that it was not possible to completely back-up a cable system with satellite capacity, so it became necessary to provide sufficient terrestrial back-up capability. Not all telecommunications organizations wish to take advantage of this capability, so modern cable systems may have dual landing points in some countries (where back-up capability is required) and only single landing points in other countries where back-up capability is either not required, the capacity to the country is small enough to be backed up by other means, or having back-up is regarded as too expensive.

A further redundant-path development over and above the self-healing rings approach is the "Mesh Network" whereby fast switching equipment is used to transfer services between network paths with little to no effect on higher-level protocols if a path becomes inoperable. As more paths become available to use between two points, the less likely it is that one or two simultaneous failures will prevent end-to-end service.

Importance of submarine cables

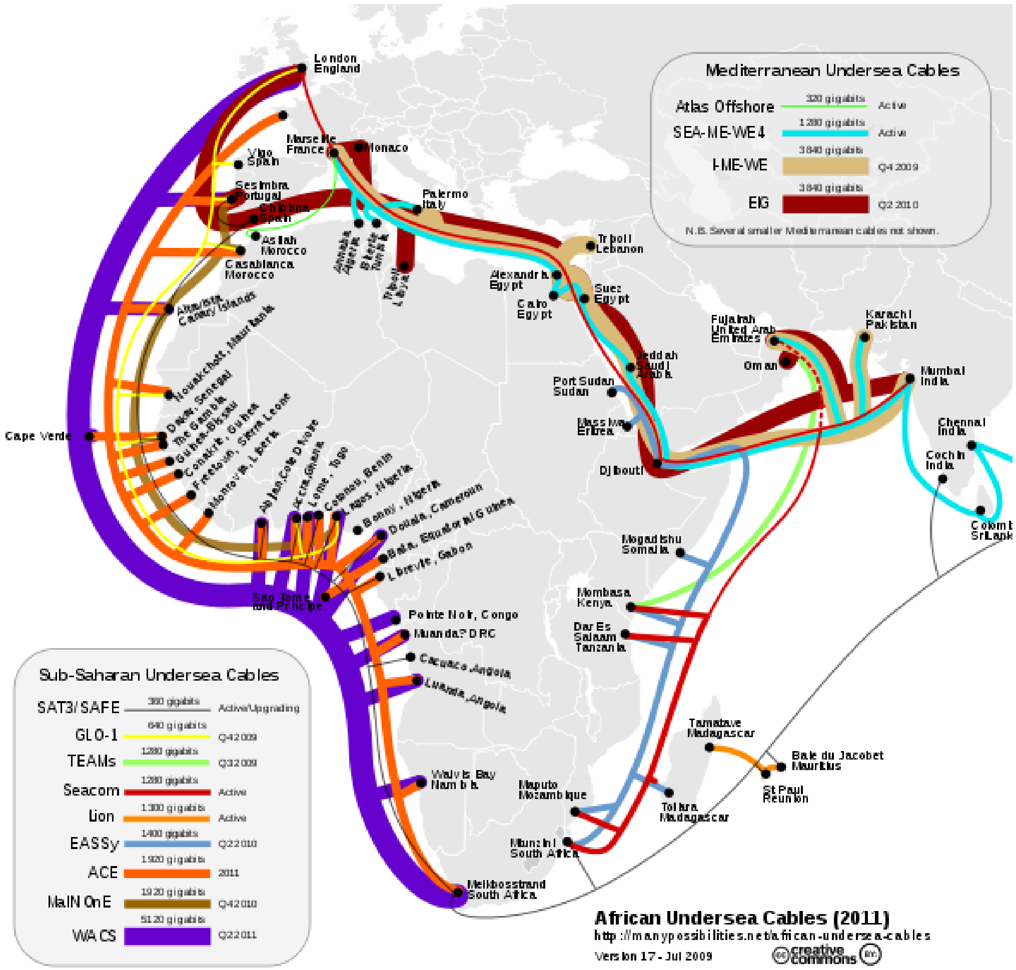
As of 2006, overseas satellite links accounted for only 1 percent of international traffic, while the remainder was carried by undersea cable. The reliability of submarine cables is high, especially when (as noted above), multiple paths are available in the event of a cable break. Also, the total carrying capacity of submarine cables is in the terabits per second while satellites typically offer only megabits per second and display higher latency. However, a typical multi-terabit, transoceanic submarine cable system costs several hundred million dollars to construct.

As a result of these cables' cost and usefulness they are highly valued not only by the corporations building and operating them for profit, but also by national governments. For instance, the Australian government considers its submarine cable systems to be “vital to the national economy.” Accordingly, the Australian Communications and Media Authority (ACMA) has created protection zones that restrict activities that could potentially damage cables linking Australia to the rest of the world. The ACMA also regulates all projects to install new submarine cables.

Investment in and financing of submarine cables

Almost all fiber optic cables from TAT-8 in 1988 until approximately 1997 were constructed by "consortia" of operators. For example, TAT-8 counted 35 participants including most major international carriers at the time such as AT&T. Two privately-financed, non-consortium cables were constructed in the late-1990s, which preceded a massive, speculative rush to construct privately-financed cables that peaked in more than $22 billion worth of investment between 1999 and 2001. This was followed by the bankruptcy and reorganization of cable operators such as Global Crossing, 360networks, FLAG, Worldcom, and Asia Global Crossing.

There has been an increasing tendency in recent years to expand submarine cable in the Pacific Ocean (the previous bias always having been to lay communications cable across the Atlantic Ocean which separates the United States and Europe). For example, between 1998 and 2003, approximately 70% of undersea fiber-optic cable was laid in the Pacific. This is in part a response to the emerging significance of Asian markets in the global economy.



A map of active and anticipated submarine communications cables servicing the African continent

Although much of the investment in submarine cables has been directed toward developed markets such as the transatlantic and transpacific routes, in recent years there has been an increased effort to expand the submarine cable network to serve the developing world. For instance, in July 2009 an underwater fiber optic cable line plugged East Africa into the broader Internet. The company that provided this new cable was SEACOM, which is 75% owned by Africans. The project is based on the hope that new information technology will reduce the cost of doing business in Africa and between Africa and other international parties. Still, the project was delayed by a month due to increased piracy along the coast, a reminder that the developing world faces other struggles that new technologies such as this may not necessarily solve.

Out of range

Antarctica is the only continent yet to be reached by a submarine telecommunications cable. All phone, video, and e-mail traffic must be relayed to the rest of the world via satellite, which is still quite unreliable. Bases on the continent itself are able to communicate with one another via radio, but this is only a local network. To be a viable alternative, the fiber-optic cable must be able to withstand temperatures of −80˚ C as well as massive strain from ice flowing up to 10 meters per year. Thus, plugging into the larger Internet backbone with the high bandwidth afforded by fiber-optic cable is still an as yet infeasible economic and technical challenge in the Antarctic.

Cable repair

Cables can be broken by fishing trawlers, anchors, earthquakes, undersea avalanches, and even shark bites. Based on surveying breaks in the Atlantic Ocean and the Caribbean Sea, it was found that between 1959 and 1996 less than 9% were due to natural events. In response to this self-imposed threat to the communications network, the practice of cable burial has developed. The average incidence of cable faults was 3.7 per 1,000 km per year from 1959 to 1979. That rate was reduced to 0.44 faults per 1,000 km per year after 1985, due to widespread burial of cable starting in 1980. Still, cable breaks are by no means a thing of the past, with more than 50 repairs a year in the Atlantic alone, and significant breaks in 2006, 2008 and 2009.

The propensity for fishing trawler nets to cause cable faults may well have been exploited during the Cold War. For example, in February 1959 a series of 12 breaks occurred in five American trans-Atlantic communications cables. In response, a United States naval vessel, the U.S.S. *Roy O. Hale* detained and investigated the Soviet trawler *Novorosiysk*. A review of the ship's log indicated it had been in the region of each of the cables when they broke. Broken sections of cable were also found on the deck of the *Novorosiysk*. It appeared that the cables had been dragged along by the ship's nets, and then cut once they were pulled up onto the deck in order to release the nets. The Soviet Union's stance on the investigation was that it was unjustified, but the United States cited the Convention for the Protection of Submarine Telegraph Cables of 1884 to which Russia had been committed (prior to the formation of the Soviet Union) as evidence of violation of international protocol.

Shore stations can locate a break in a cable by electrical measurements, such as through spread-spectrum time-domain reflectometry (SSTDR). SSTDR is a type of time-domain reflectometry that can be used in live environments very quickly. Presently SSTDR can collect a complete data set in 20ms. Spread spectrum signals are sent down the wire and then the reflected signal is observed. It is then correlated with the copy of the sent signal and mathematical algorithms are applied to the shape and timing of the signals to locate the break.

A repair ship will be sent to the location to drop a marker buoy near the break. Several types of grapples are used depending on the situation. If the sea bed in question is sandy, a grapple with rigid prongs is used to plough under the surface and catch the cable. If the cable is on a rocky sea surface, the grapple is more flexible, with hooks along its length so that it can adjust to the changing surface. In especially deep water, the cable may not be strong enough to lift as a single unit, so a special grapple that cuts the cable soon after it has been hooked is used and only one length of cable is brought to the surface at a time, whereupon a new section is spliced in. The repaired cable is longer than the original, so the excess is deliberately laid in a 'U' shape on the seabed. A submersible can be used to repair cables that lie in shallower waters.

A number of ports near important cable routes became homes to specialised cable repair ships. Halifax, Nova Scotia was home to a half dozen such vessels for most of the 20th century including long-lived vessels such as the CS *Cyrus West Field*, CS *Minia* and *CS Mackay-Bennett*. The latter two were contracted to recover victims from the sinking of the RMS *Titanic*. The crews of these vessels developed many new techniques and devices to repair and improve cable laying, such as the "plough".

Intelligence gathering

Underwater cables, which cannot be kept under constant surveillance, have tempted intelligence-gathering organizations since the late 19th century. Frequently at the beginning of wars nations have cut the cables of the other sides in order to shape the information flows into cables that were being monitored. The most ambitious efforts occurred in World War I, when British and German forces systematically attempted to destroy the others' worldwide communications systems by cutting their cables with surface ships or submarines. During the Cold War the United States Navy and National Security Agency (NSA) succeeded in placing wire taps on Soviet underwater communication lines in Operation Ivy Bells.

Environmental impact

The main point of interaction of cables with marine life is in the benthic zone of the oceans where the majority of cable lies. Recent studies (in 2003 and 2006) have indicated that cables pose minimal impacts on life in these environments. In sampling sediment cores around cables and in areas removed from cables, there were few statistically significant differences in organism diversity or abundance. The main difference was that the cables provided an attachment point for anemones that typically could not grow in soft sediment areas. Data from 1877 to 1955 showed a total of 16 cable faults caused by the entanglement of various whales, but such deadly entanglements have entirely ceased after the transition from telegraph cables to coaxial cables and then fiber-optic cables (the new cables are better designed in terms of torsional balance so that they have less of a tendency to coil).