Electrical Wiring
(Insulated Conductors)

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Electrical Wiring

Electrical wiring in general refers to insulated conductors used to carry electricity, and associated devices. Here we, describes general aspects of electrical wiring as used to provide power in buildings and structures, commonly referred to as **building wiring**.

Wiring safety codes

Wiring safety codes are intended to protect people and buildings from electrical shock and fire hazards. Regulations may be established by city, county, provincial/state or national legislation, sometimes by adopting in amended form a model code produced by a technical standards-setting organization, or by a national standard electrical code.

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

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

Since 1927, the Canadian Standards Association (CSA) has produced the Canadian *Safety Standard for Electrical Installations*, which is the basis for provincial electrical codes. The CSA also produces the Canadian Electrical Code, the 2006 edition of which references IEC 60364 (*Electrical Installations for Buildings*) and states that the code addresses the fundamental principles of electrical protection in Section 131. The Canadian code reprints Chapter 13 of IEC 60364, and it is interesting to note that there are no numerical criteria listed in that chapter whereby the adequacy of any electrical installation can be assessed.

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

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

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

In the United Kingdom wiring installations are regulated by the Institution of Engineering and Technology *Requirements for Electrical Installations: IEE Wiring Regulations, BS 7671: 2008,* which are harmonised with IEC 60364. The previous edition (16th) was replaced by the current 17th Edition in January 2008. The 17th edition includes new sections for microgeneration and solar photovoltaic systems. The first edition was published in 1882.

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

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

Colour code

To enable wires to be easily and safely identified, all common wiring safety codes mandate a colour scheme for the insulation on power conductors. Many local rules and exceptions exist. Older installations vary in colour codes, and colours may shift with heat and age of insulation.

Standard wire colours for FLEXIBLE cable
(e.g. Extension cords, power (line) cords and lamp cords)

Region or Country	Phases	Neutral	Protective earth/ground
European Union (EU), Australia, South Africa (IEC 60446)	brown	blue	green/yellow
Australia, New Zealand (AS/NZS 3000:2007 3.8.1)	brown	light blue	green/yellow
United States, Canada	black (*brass*)	white (*silver*)	green (*green*)

Standard wire colours for FIXED cable
(e.g. In-, On-, or Behind-the-wall wiring cables)

Region or Country	Phases	Neutral	Protective earth/ground
European Union (EU) (IEC 60446) including UK from 31 March 2004	brown, black, grey	blue	green/yellow
UK prior to 31 March 2004	red, yellow, blue	black	green/yellow green (formerly) bare conductor, sleeved at terminations (formerly)
Australia	red	black	green/yellow (since about 1980) green (since about 1980) bare conductor, sleeved at terminations (formerly)
South Africa	red	black	green/yellow bare conductor, sleeved at terminations
United States	black, red, blue (120/208/240V) (*brass*) brown, orange,	white (120/208/240V) (*silver*)	green (*green*) bare conductor green/yellow (isolated

	yellow (277/480V)	grey(277/480V)	ground)
Canada	red, black (120/208/240V) red, black, blue (600/347V)	white (120/208/240V) white (600/347V)	green (*green*) bare conductor green (isolated ground)

Notes:

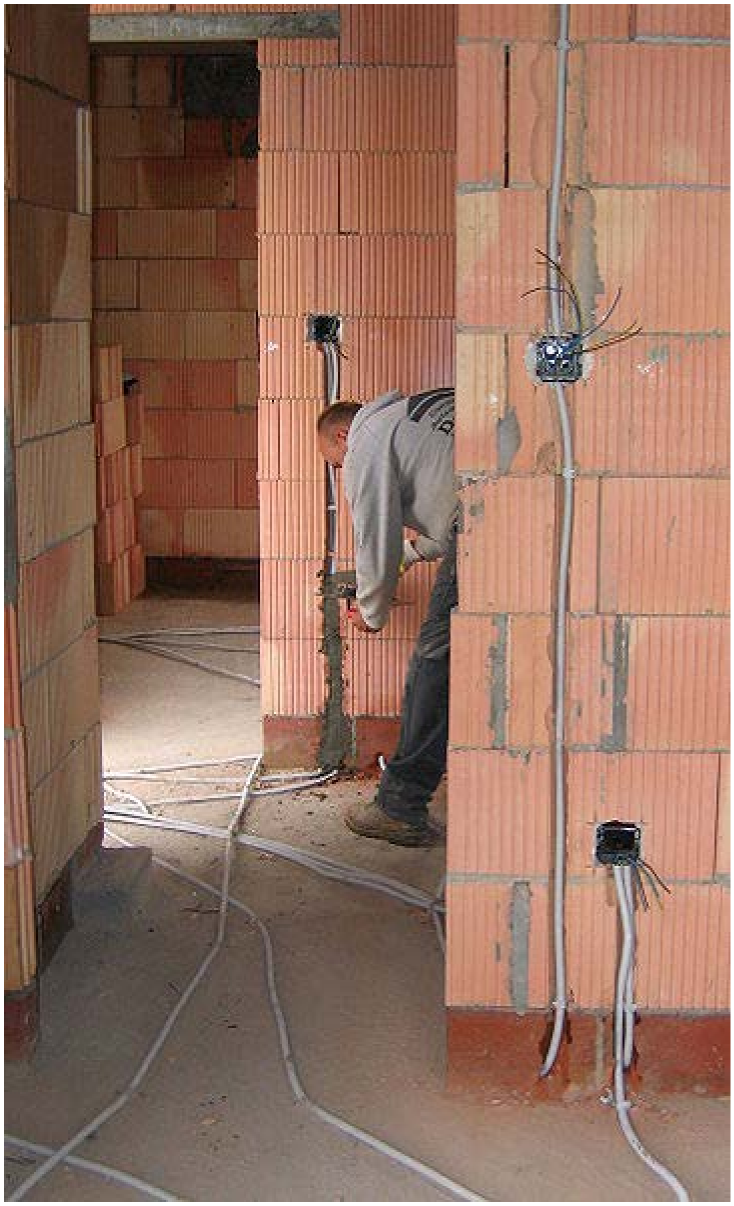
Parenthesized colours in *italics* are used on metallic terminals.

"Green/yellow" means green with yellow stripe.

The colours in this table represent the most common and preferred standard colours for wiring; however others may be in use, especially in older installations.

The Canadian and American wiring standards are very similar with small differences, and have different operating voltages in ICI applications.

Wiring methods



Installing electrical wiring by cutting into the bricks of the building

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

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

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

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

Early wiring methods

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

Knob and tube

Knob-and-Tube wiring

The earliest standardized method of wiring in buildings, in common use in North America from about 1880 to the 1930s, was *knob and tube* (K&T) wiring: single conductors were run through cavities between the structural members in walls and ceilings, with ceramic tubes forming protective channels through joists and ceramic knobs attached to the structural members to provide air between the wire and the lumber and to support the wires. Since air was free to circulate over the wires, smaller conductors could be used than required in cables. By arranging wires on opposite sides of building structural members, some protection was afforded against short-circuits that can be caused by driving a nail into both conductors simultaneously. By the 1940s, the labour cost of installing two conductors rather than one cable resulted in a decline in new knob-and-tube installations.

Metal-sheathed wires

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

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

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

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

Other historical wiring methods

Other methods of securing wiring that are now obsolete include:

- Re-use of existing gas pipes for electric lighting. Insulated conductors were pulled into the pipes feeding gas lamps.
- Wood mouldings with grooves cut for single conductor wires, covered by a wooden cap strip. These were prohibited in North American electrical codes by 1928. Wooden moulding was also used to some degree in England, but was never permitted by German and Austrian rules.
- A system of flexible twin cords supported by glass or porcelain buttons was used near the turn of the 20th century in Europe, but was soon replaced by other methods.
- During the first years of the 20th century various patented forms of wiring system such as Bergman and Peschel tubing were used to protect wiring; these used very thin fibre tubes or metal tubes which were also used as return conductors.
- In Austria, wires were concealed by embedding a rubber tube in a groove in the wall, plastering over it and then removing the tube and pulling in wires in the cavity.

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

Cables

Wiring in extremely-wet conditions

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

The first polymer-insulated cables for building wiring were introduced in 1922. These were two or more solid copper wires, with rubber insulation, woven cotton cloth over each conductor for protection of the insulation, with an overall woven jacket, usually impregnated with tar as a protection from moisture. Waxed paper was used as a filler and separator.

Rubber-insulated cables become brittle over time because of exposure to oxygen, so they must be handled with care, and should be replaced during renovations. When switches, outlets or light fixtures are replaced, the mere act of tightening connections may cause insulation to flake off the conductors. Rubber was hard to separate from bare copper, so copper was tinned, causing slightly more resistance.

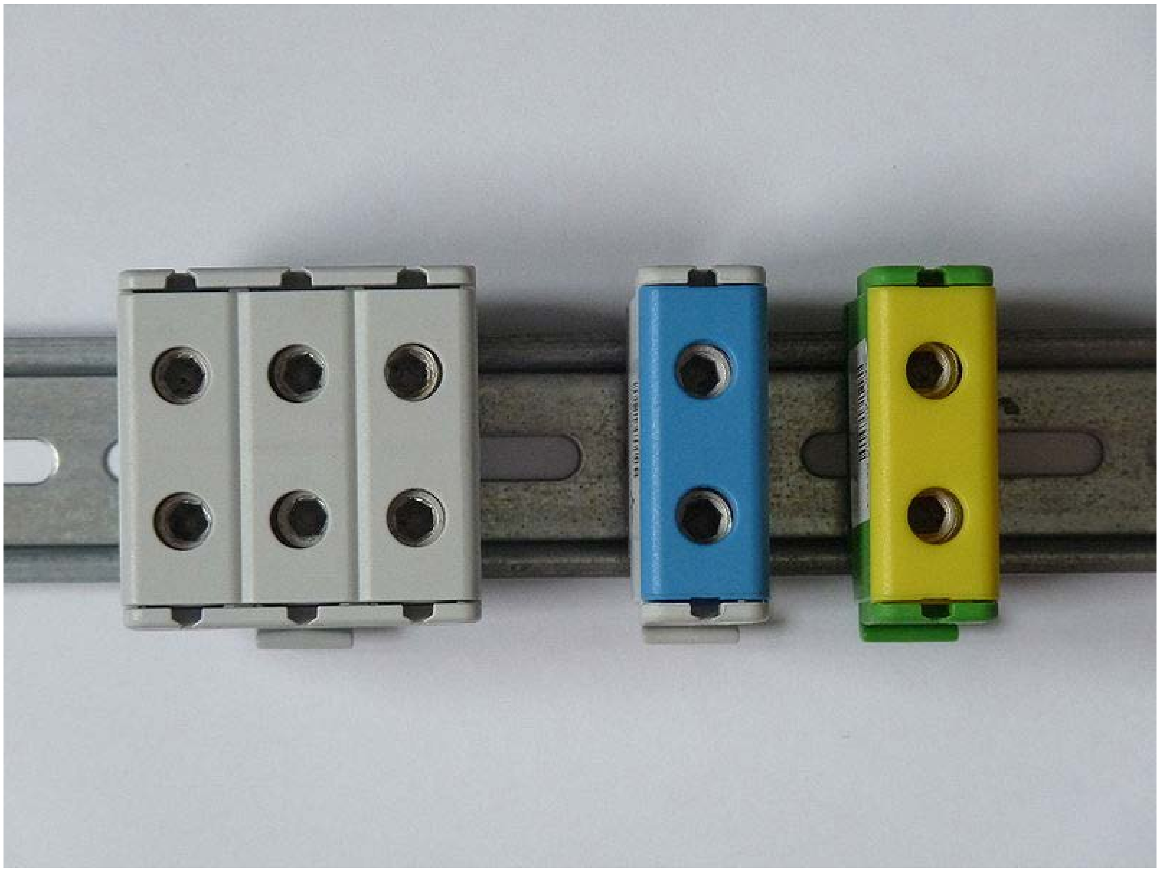
Three-phase copper cable TN-S 16mm² (5AWG) with PVC insulation

About 1950, PVC insulation and jackets were introduced, especially for residential wiring. About the same time, single conductors with a thinner PVC insulation and a thin nylon jacket became common.

The simplest form of cable has two insulated conductors twisted together to form a unit; such unjacketed cables with two or three conductors are used for low-voltage signal and control applications such as doorbell wiring. In North American practice, an overhead cable from a transformer on a power pole to a residential electrical service consists of three twisted (triplexed) wires, often with one being a bare copper wire (protective earth/ground) and the other two being insulated for the line voltage (hot/live wire and neutral wire).

Aluminium conductors

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



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

Aluminium conductors were originally used with wiring devices intended for copper wires. This can cause defective connections unless the aluminium was one of a special alloy, or all devices — breakers, switches, receptacles, splice connectors, i.e., wire nuts, etc. — were designed to address problems with junctions between dissimilar metals, oxidation on metal surfaces and mechanical effects that occur as different metals expand at different rates with increases in temperature. Unlike copper, aluminium has a tendency to cold-flow under pressure, so screw clamped connections may get loose over time. This can be mitigated by using spring-loaded connectors that apply constant pressure, applying high pressure cold joints in splices and termination fittings, and torquing the bolted connection. Unlike copper, aluminium forms an insulating oxide layer on the surface. This is sometimes addressed by coating aluminium wires with an antioxidant paste at joints, or applying a mechanical termination designed to break through the oxide layer during installation.

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

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

Modern wiring materials

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

Modern nonmetallic sheathed cables (NMC), like (U.S. and Canadian) Type NM, consist of two to four wires covered with thermoplastic insulation and a bare wire for grounding (bonding) surrounded by a flexible plastic jacket. Some versions wrap the individual conductors in paper before the plastic jacket is applied. It is often called **Romex™** cable, since the first of its type was manufactured by Rome Cable Division of Cyprus Mines, Rome, New York. The trade name has been owned by Southwire since it purchased the electrical building wire assets of General Cable in 2001.

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

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

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

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

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

Mineral insulated cables at a panel board

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

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

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

Raceways

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

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

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

A cable tray can be used in stores and dwellings

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

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

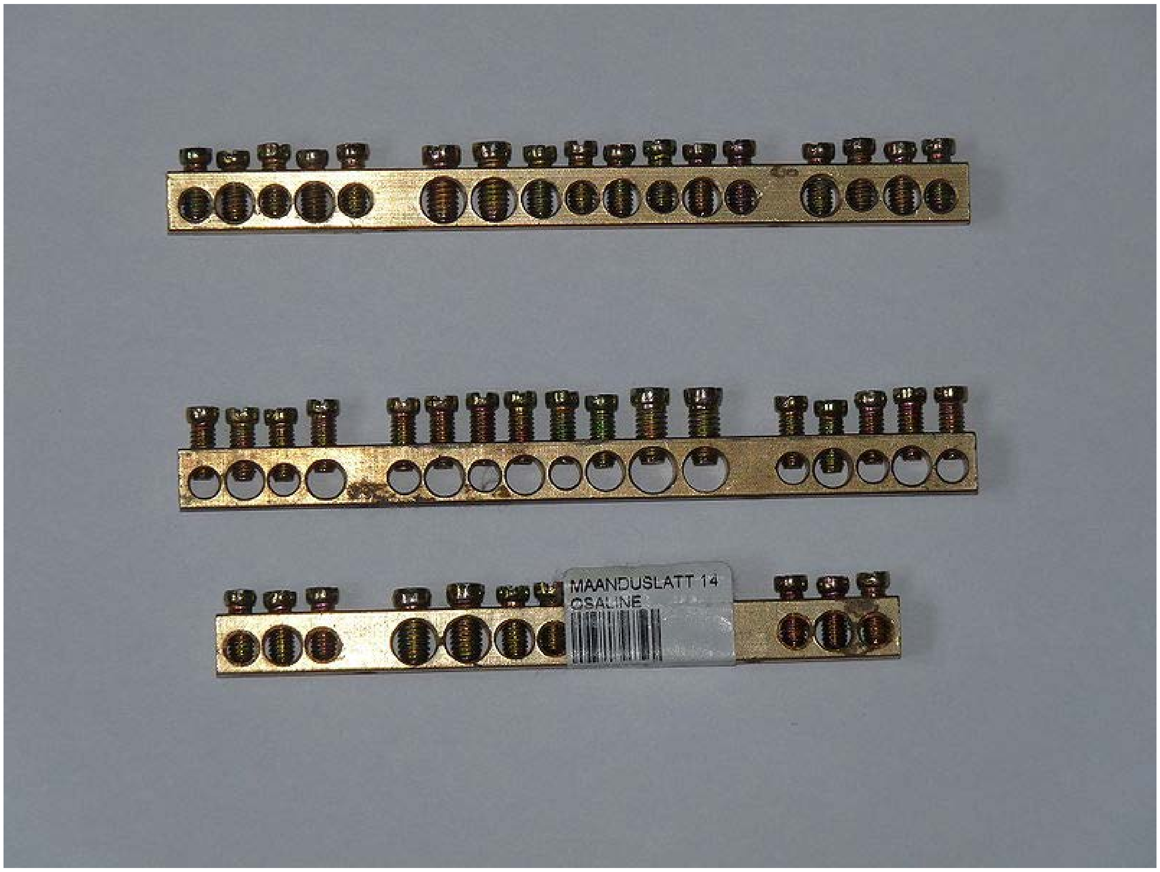
Special fittings are used for wiring in potentially explosive atmospheres.

Bus bars, bus duct, cable bus

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

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

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



Busbars for distributing PE (ground)

Bus ducts may have all phase conductors in the same enclosure (non-isolated bus), or may have each conductor separated by a grounded barrier from the adjacent phases (segregated bus). For conducting large currents between devices, a cable bus is used. For very large currents in generating stations or substations, where it is difficult to provide circuit protection, an isolated-phase bus is used. Each phase of the circuit is run in a separate grounded metal enclosure. The only fault possible is a phase-to-ground fault, since the enclosures are separated. This type of bus can be rated up to 50,000 amperes and up to hundreds of kilovolts (during normal service, not just for faults), but is not used for building wiring in the conventional sense.

Electrical panels

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

Electrical panels, cables and firestops in an electrical service room at St. Mary's Pulp and Paper, a paper mill in Sault Ste. Marie, Ontario, Canada.

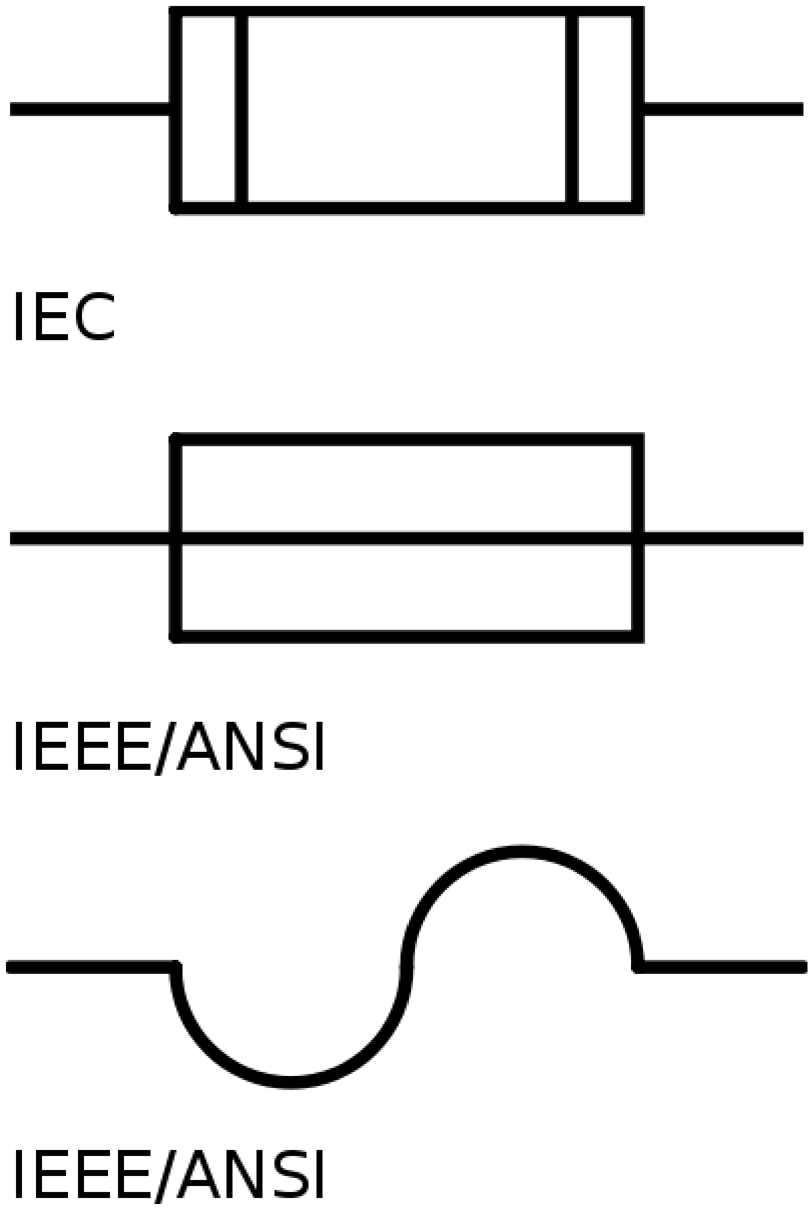
Electrical panels are easily accessible junction boxes used to reroute and switch electrical services.

Chapter-2

Fuse

A miniature time-delay fuse used to protect electronic equipment, rated 0.3 amperes at 250 volts. 1.25 inches (about 32 mm) long.

200 A Industrial fuse. 80 kA breaking capacity.



Electronic symbols for a fuse. IEC (upper) and IEEE/ANSI American/Canadian (lower two) versions.

In electronics and electrical engineering a **fuse** (from the French *fusée*, Italian. *fuso*, "spindle") is a type of sacrificial overcurrent protection device. Its essential component is a metal wire or strip that melts when too much current flows, which interrupts the circuit in which it is connected. Short circuit, overload or device failure is often the reason for excessive current.

A fuse interrupts excessive current (blows) so that further damage by overheating or fire is prevented. Wiring regulations often define a maximum fuse current rating for particular circuits. Overcurrent protection devices are essential in electrical systems to limit threats to human life and property damage. Fuses are selected to allow passage of normal current and of excessive current only for short periods.

In 1847, Breguet recommended use of reduced-section conductors to protect telegraph stations from lightning strikes; by melting, the smaller wires would protect apparatus and wiring inside the building. A variety of wire or foil fusible elements were in use to protect telegraph cables and lighting installations as early as 1864.

A fuse was patented by Thomas Edison in 1890 as part of his successful electric distribution system.

Operation

A fuse consists of a metal strip or wire fuse element, of small cross-section compared to the circuit conductors, mounted between a pair of electrical terminals, and (usually) enclosed by a non-conducting and non-combustible housing. The fuse is arranged in series to carry all the current passing through the protected circuit. The resistance of the element generates heat due to the current flow. The size and construction of the element is (empirically) determined so that the heat produced for a normal current does not cause the element to attain a high temperature. If too high a current flows, the element rises to a higher temperature and either directly melts, or else melts a soldered joint within the fuse, opening the circuit.

When the metal conductor parts, an electric arc forms between the un-melted ends of the element. The arc grows in length until the voltage required to sustain the arc is higher than the available voltage in the circuit, terminating current flow. In alternating current circuits the current naturally reverses direction on each cycle, greatly enhancing the speed of fuse interruption. In the case of a current-limiting fuse, the voltage required to sustain the arc builds up quickly enough to essentially stop the fault current before the first peak of the AC waveform. This effect significantly limits damage to downstream protected devices.

The fuse element is made of zinc, copper, silver, aluminum, or alloys to provide stable and predictable characteristics. The fuse ideally would carry its rated current indefinitely, and melt quickly on a small excess. The element must not be damaged by minor harmless surges of current, and must not oxidize or change its behavior after possibly years of service.

The fuse elements may be shaped to increase heating effect. In large fuses, current may be divided between multiple strips of metal. A dual-element fuse may contain a metal strip that melts instantly on a short-circuit, and also contain a low-melting solder joint that responds to long-term overload of low values compared to a short-circuit. Fuse elements may be supported by steel or nichrome wires, so that no strain is placed on the element, but a spring may be included to increase the speed of parting of the element fragments.

The fuse element may be surrounded by air, or by materials intended to speed the quenching of the arc. Silica sand or non-conducting liquids may be used.

Characteristic parameters

Rated current I_N

A maximum current that the fuse can continuously conduct without interrupting the circuit.

Speed

The speed at which a fuse blows depends on how much current flows through it and the material of which the fuse is made. The operating time is not a fixed interval, but decreases as the current increases. Fuses have different characteristics of operating time compared to current, characterized as *fast-blow*, *slow-blow*, or *time-delay*, according to time required to respond to an overcurrent condition. A standard fuse may require twice its rated current to open in one second, a fast-blow fuse may require twice its rated current to blow in 0.1 seconds, and a slow-blow fuse may require twice its rated current for tens of seconds to blow.

Fuse selection depends on the load's characteristics. Semiconductor devices may use a fast or *ultrafast* fuse since semiconductor devices heat rapidly when excess current flows. The fastest blowing fuses are designed for the most sensitive electrical equipment, where even a short exposure to an overload current could be very damaging. Normal fast-blow fuses are the most general purpose fuses. The time delay fuse (also known as anti-surge, or slow-blow) are designed to allow a current which is above the rated value of the fuse to flow for a short period of time without the fuse blowing. These types of fuse are used on equipment such as motors, which can draw larger than normal currents for up to several seconds while coming up to speed.

The I^2t value

A measure of energy required to blow the fuse element and so a measure of the damaging effect of overcurrent on protected devices; sometimes known as the let-through energy. Unique I^2t parameters are provided by charts in manufacturer data sheets for each fuse family. The energy is mainly dependent on current and time for fuses.

Breaking capacity

The breaking capacity is the maximum current that can safely be interrupted by the fuse. Generally, this should be higher than the prospective short circuit current. Miniature fuses may have an interrupting rating only 10 times their rated current. Some fuses are designated High Rupture Capacity (HRC) and are usually filled with sand or a similar material. Fuses for small, low-voltage, usually residential, wiring systems are commonly rated, in North American practice, to interrupt 10,000 amperes. Fuses for larger power systems must have higher interrupting ratings, with some low-voltage current-limiting high interrupting fuses rated for 300,000 amperes. Fuses for high-voltage equipment, up to 115,000 volts, are rated by the total apparent power (megavolt-amperes, MVA) of the fault level on the circuit.

Rated voltage

Voltage rating of the fuse must be greater than or equal to what would become the open circuit voltage. For example, a glass tube fuse rated at 32 volts would not reliably interrupt current from a voltage source of 120 or 230 V. If a 32 V fuse attempts to interrupt the 120 or 230 V source, an arc may result. Plasma inside that glass tube fuse may continue to conduct current until current eventually so diminishes that plasma reverts to an insulating gas. Rated voltage should be larger than the maximum voltage source it would have to disconnect. This requirement applies to every type of fuse.

Rated voltage remains same for any one fuse, even when similar fuses are connected in series. Connecting fuses in series does not increase the rated voltage of the combination (nor of any one fuse).

Medium-voltage fuses rated for a few thousand volts are never used on low voltage circuits, because of their cost and because they cannot properly clear the circuit when operating at very low voltages.

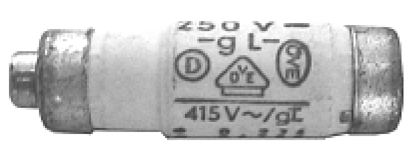
Voltage drop

A voltage drop across the fuse is usually provided by its manufacturer. Resistance may change when a fuse becomes hot due to energy dissipation while conducting higher currents. This resulting voltage drop should be taken into account, particularly when using a fuse in low-voltage applications. Voltage drop often is not significant in more traditional wire type fuses, but can be significant in other technologies such as resettable fuse (PPTC) type fuses.

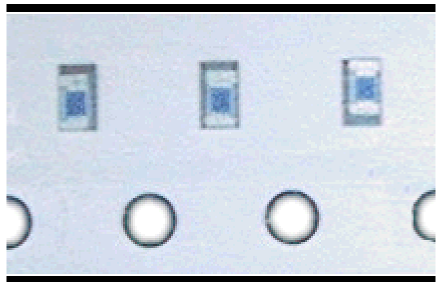
Temperature derating

Ambient temperature will change a fuse's operational parameters. A fuse rated for 1 A at 25 °C may conduct up to 10% or 20% more current at −40 °C and may open at 80% of its rated value at 100 °C. Operating values will vary with each fuse family and are provided in manufacturer data sheets.

Markings



A sample of the many markings that can be found on a fuse.



Surface Mount Fuses on 8 mm tape. Each fuse measures 1.6 mm × 0.79 mm and has no markings.

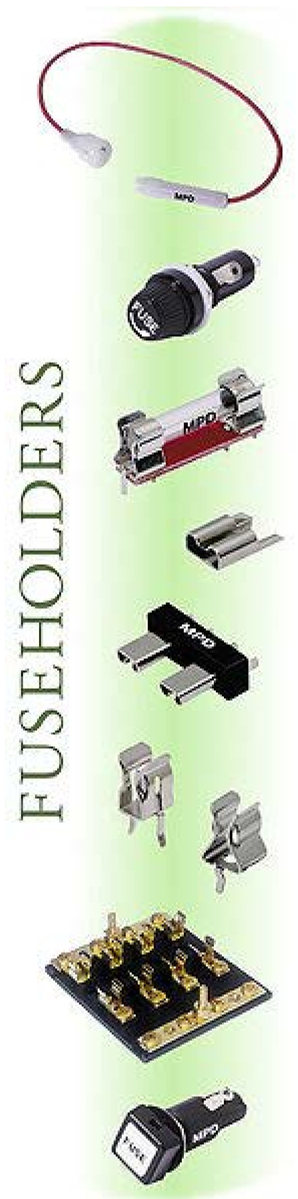
Most fuses are marked on the body or end caps with markings that indicate their ratings. Surface-mount technology "chip type" fuses feature few or no markings, making identification very difficult.

Similar appearing fuses may have significantly different properties, identified by their markings. Fuse markings will generally convey the following information, either explicitly as text, or else implicit with the approval agency marking for a particular type:

- Ampere rating of the fuse.
- Voltage rating of the fuse.
- Time-current characteristic; i.e. fuse speed.
- Approvals by national and international standards agencies.
- Manufacturer/part number/series.
- Breaking capacity

Packages and materials

Fuses come in a vast array of sizes and styles to serve in many applications, manufactured in standardised package layouts to make them easily interchangeable. Fuse bodies may be made of ceramic, glass, plastic, fiberglass, molded mica laminates, or molded compressed fibre depending on application and voltage class.



Multiple fuseholders.

Cartridge (ferrule) fuses have a cylindrical body terminated with metal end caps. Some cartridge fuses are manufactured with end caps of different sizes to prevent accidental insertion of the wrong fuse rating in a holder, giving them a bottle shape.

Fuses for low voltage power circuits may have bolted blade or tag terminals which are secured by screws to a fuseholder. Some blade-type terminals are held by spring clips. Blade type fuses often require the use of a special purpose extractor tool to remove them from the fuse holder.

Renewable fuses have replaceable fuse elements, allowing the fuse body and terminals to be reused if not damaged after a fuse operation.

Fuses designed for soldering to a printed circuit board have radial or axial wire leads. Surface mount fuses have solder pads instead of leads.

High-voltage fuses of the expulsion type have fiber or glass-reinforced plastic tubes and an open end, and can have the fuse element replaced.

Semi-enclosed fuses are fuse wire carriers in which the fusible wire itself can be replaced. These are used in consumer units in some parts of the world, but are becoming less common.

While glass fuses have the advantage of a fuse element visible for inspection purposes, they have a low breaking capacity which generally restricts them to applications of 15 A or less at 250 V_{AC}. Ceramic fuses have the advantage of a higher breaking capacity, facilitating their use in circuits with higher current and voltage. Filling a fuse body with sand provides additional cooling of the arc and increases the breaking capacity of the fuse. Medium-voltage fuses may have liquid-filled envelopes to assist in the extinguishing of the arc. Some types of distribution switchgear use fuse links immersed in the oil that fills the equipment.

Fuse packages may include a rejection feature such as a pin, slot, or tab, which prevents interchange of otherwise similar appearing fuses. For example, fuse holders for North American class RK fuses have a pin that prevents installation of similar-appearing class H fuses, which have a much lower breaking capacity and a solid blade terminal that lacks the slot of the RK type.

Dimensions

Fuses can be built with different sized enclosures to prevent interchange of different ratings or types of fuse. For example, *bottle style* fuses distinguish between ratings with different cap diameters. Automotive glass fuses were made in different lengths, to prevent high-rated fuses being installed in a circuit intended for a lower rating.

Special features

Glass cartridge and plug fuses allow direct inspection of the fusible element. Other fuses have other indication methods including:

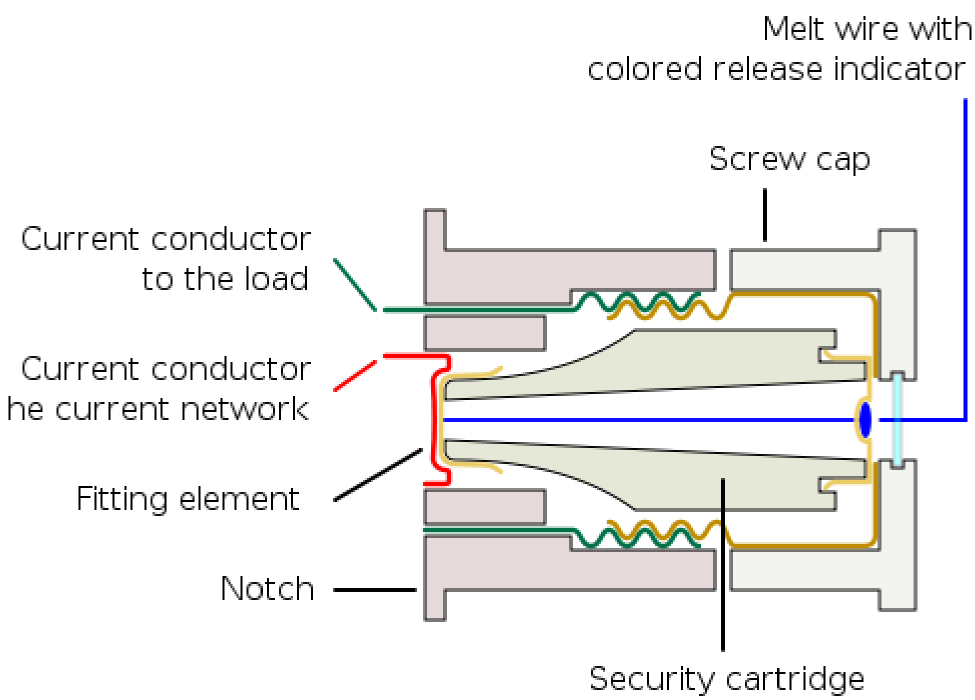
- Indicating pin or striker pin — extends out of the fuse cap when the element is blown.
- Indicating disc — a coloured disc (flush mounted in the end cap of the fuse) falls out when the element is blown.
- Element window — a small window built into the fuse body to provide visual indication of a blown element.
- External trip indicator — similar function to striker pin, but can be externally attached (using clips) to a compatible fuse.

Some fuses allow a special purpose micro switch or relay unit to be fixed to the fuse body. When the fuse element blows, the indicating pin extends to activate the micro switch or relay, which, in turn, triggers an event.

Some fuses for medium-voltage applications use two separate barrels and two fuse elements in parallel.

Fuse standards

IEC 60269 fuses



Cross section of a screw-type fuse holder with Diazed fuse

The International Electrotechnical Commission publishes standard 60269 for low-voltage power fuses. The standard is in four volumes, which describe general requirements, fuses for industrial and commercial applications, fuses for residential applications, and fuses to protect semiconductor devices. The IEC standard unifies several national standards, thereby improving the interchangeability of fuses in international trade. All fuses of different technologies tested to meet IEC standards will have similar time-current characteristics, which simplifies design and maintenance.

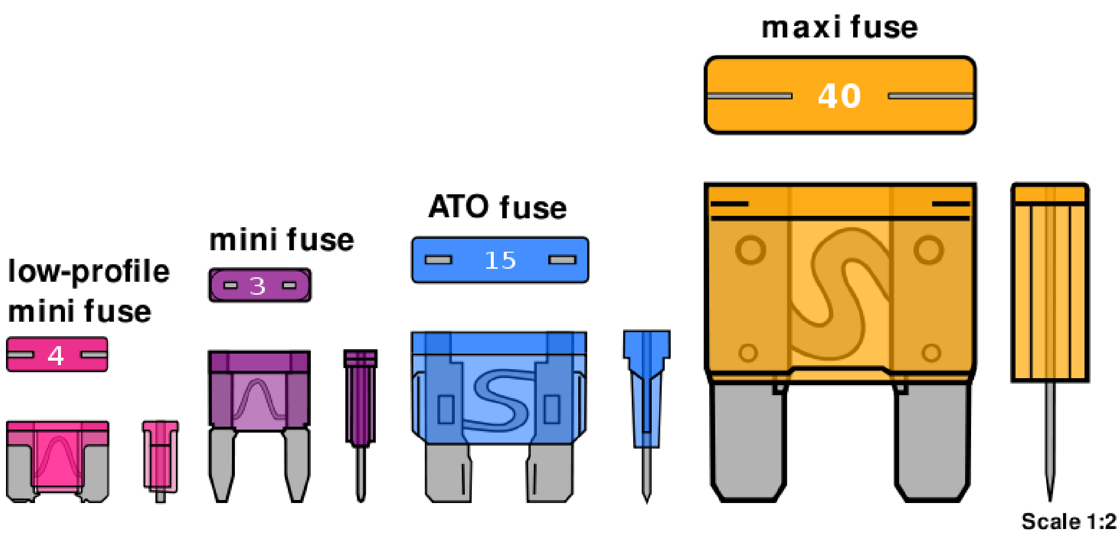
UL 248 fuses (North America)

In the United States and Canada, low-voltage fuses to 1 kV AC rating are made in accordance with Underwriters Laboratories standard UL 248 or the harmonized Canadian

Standards Association standard C22.2 No. 248. This standard applies to fuses rated 1 kV or less, AC or DC, and with breaking capacity up to 200 kA. These fuses are intended for installations following Canadian Electrical Code, Part I (CEC), or the National Electrical Code, NFPA 70 (NEC).

IEC and UL nomenclature varies slightly. IEC standards refer to a "fuse" as the assembly of a fuse link and fuse holder. In North American standards, the *fuse* is the replaceable portion of the assembly, and a *fuse link* would be a bare metal element for installation in a fuse.

Automotive fuses



Blade type fuses come in four physical sizes: low-profile mini, mini, regular and maxi

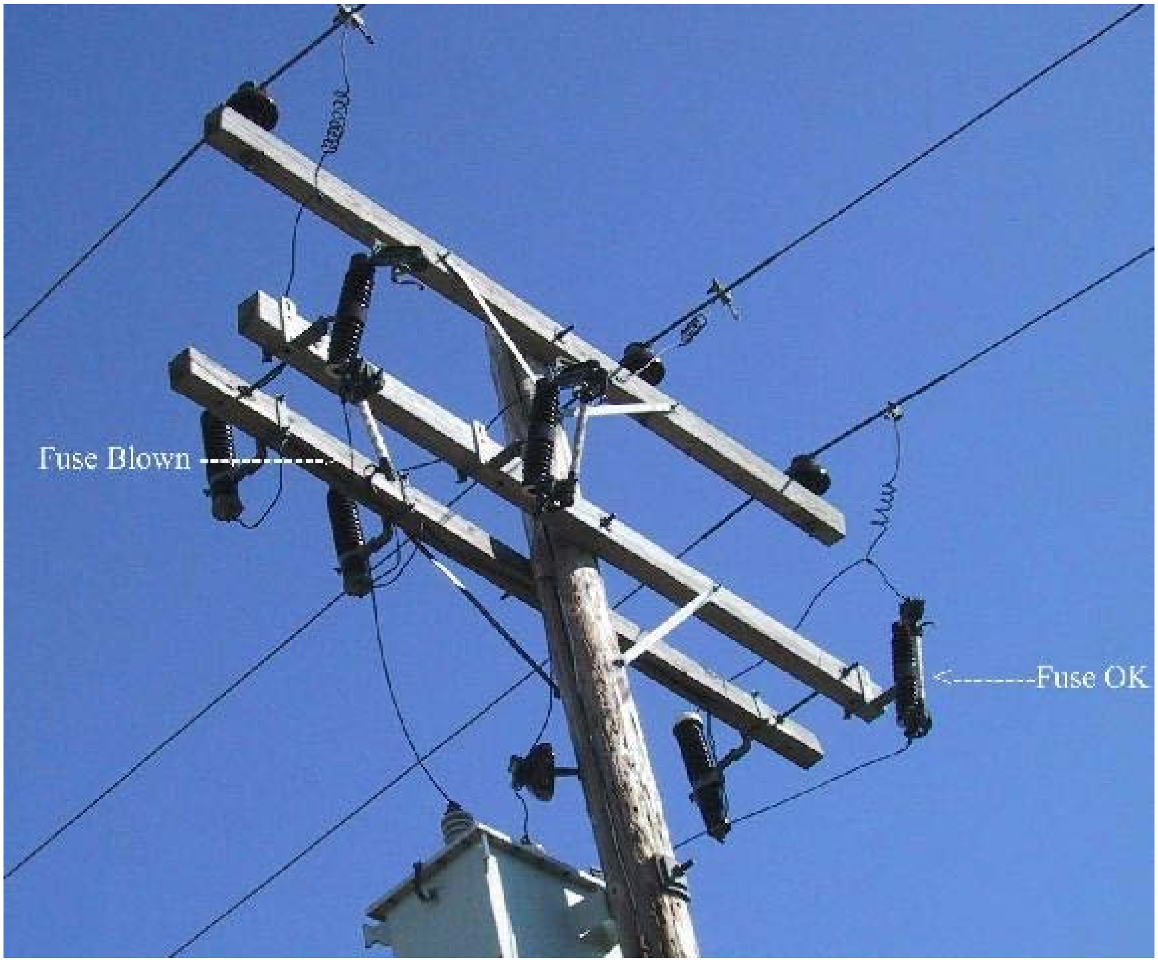
Automotive fuses are used to protect the wiring and electrical equipment for vehicles. There are several different types of automotive fuses and their usage is dependant upon the specific application, voltage, and current demands of the electrical circuit. Automotive fuses can be mounted in fuse blocks, inline fuse holders, or fuse clips. Some automotive fuses are occasionally used in non-automotive electrical applications. Standards for automotive fuses are published by SAE International (formerly known as the Society of Automotive Engineers).

Automotive fuses can be classified into four distinct categories:

- Blade fuses
- Glass tube or Bosch type
- Fusible links
- Fuse limiters

Most automotive fuses rated at 32 volts are used on circuits rated 24 volts DC and below. Some vehicles use a dual 12/42 V DC electrical system that will require a fuse rated at 58 V DC.

High voltage fuses



A set of pole-top fusible cutouts with one fuse blown, protecting a transformer- the white tube on the left is hanging down

Fuses are used on power systems up to 115,000 volts AC. High-voltage fuses are used to protect instrument transformers used for electricity metering, or for small power transformers where the expense of a circuit breaker is not warranted. For example, in distribution systems, a power fuse may be used to protect a transformer serving 1–3 houses. A circuit breaker at 115 kV may cost up to five times as much as a set of power fuses, so the resulting saving can be tens of thousands of dollars. Pole-mounted distribution transformers are nearly always protected by a fusible cutout, which can have the fuse element replaced using live-line maintenance tools.

Large power fuses use fusible elements made of silver, copper or tin to provide stable and predictable performance. High voltage *expulsion fuses* surround the fusible link with gasevolving substances, such as boric acid. When the fuse blows, heat from the arc causes the boric acid to evolve large volumes of gases. The associated high pressure (often greater than 100 atmospheres) and cooling gases rapidly quench the resulting arc. The hot gases are then explosively expelled out of the end(s) of the fuse. Such fuses can only be used outdoors.

A 115 kV high-voltage fuse in a substation near a hydroelectric power plant.

Older medium-voltage fuse for a 20 kV network

High voltage high power fuses are standalone protective switching devices used to 115 kV. They are used in power supply networks and for distribution uses. The most frequent application is in transformer circuits, with further uses in motor circuits and capacitor banks. These type of fuses may have an impact pin to operate a switch mechanism, so that all three phases are interrupted if any one fuse blows.

High-power fuse means that these fuses can interrupt several kiloamperes. Some manufacturers have tested their fuses for up to 63 kA cut-off current.

Fuses compared with circuit breakers

Fuses have the advantages of often being less costly and simpler than a circuit breaker for similar ratings. The blown fuse must be replaced with a new device which is less convenient than simply resetting a breaker and therefore likely to discourage people from ignoring faults. On the other hand, replacing a fuse without isolating the circuit first (most building wiring designs do not provide individual isolation switches for each fuse) can be dangerous in itself, particularly if the fault is a short circuit.

High rupturing capacity fuses can be rated to safely interrupt up to 300,000 amperes at 600 V AC. Special current-limiting fuses are applied ahead of some molded-case breakers to protect the breakers in low-voltage power circuits with high short-circuit levels.

Current-limiting fuses operate so quickly that they limit the total "let-through" energy that passes into the circuit, helping to protect downstream equipment from damage. These fuses open in less than one cycle of the AC power frequency; circuit breakers cannot match this speed.

Some types of circuit breakers must be maintained on a regular basis to ensure their mechanical operation during an interruption. This is not the case with fuses, which rely on melting processes where no mechanical operation is required for the fuse to operate under fault conditions.

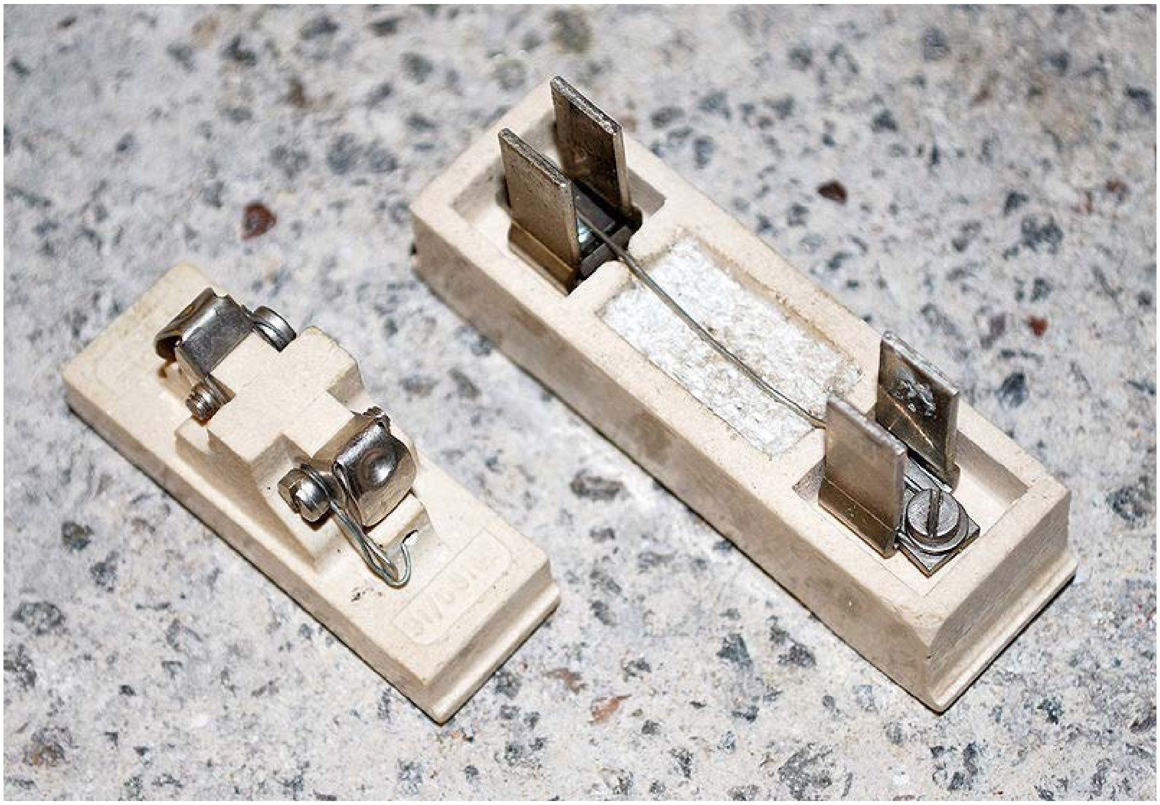
In a multi-phase power circuit, if only one fuse opens, the remaining phases will have higher than normal currents, and unbalanced voltages, with possible damage to motors. Fuses only sense overcurrent, or to a degree, over-temperature, and cannot usually be used independently with protective relaying to provide more advanced protective functions, for example, ground fault detection.

Some manufacturers of medium-voltage distribution fuses combine the overcurrent protection characteristics of the fusible element with the flexibility of relay protection by adding a pyrotechnic device to the fuse operated by external protective relays.

Fuse boxes

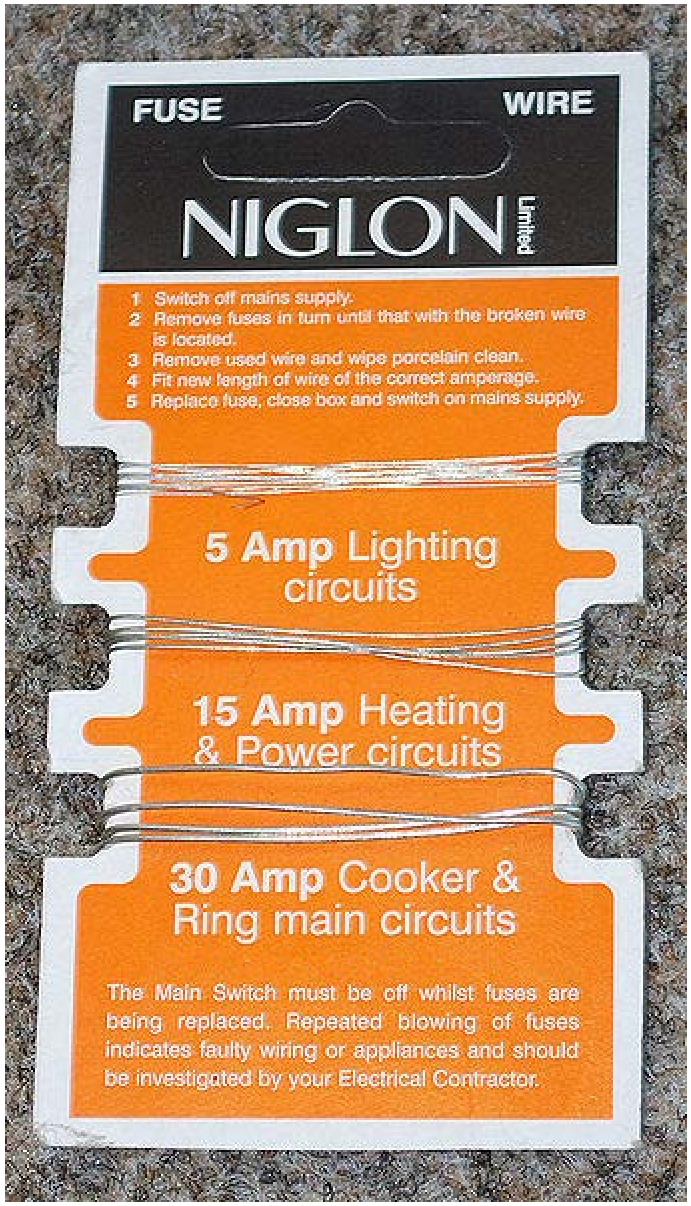
Rewirable fuses

MEM rewirable fuse box



MEM rewirable fuse holders (30 A and 15 A)

Wylex fuse box



fuse wire as sold to UK consumers

In the UK, older electrical consumer units (also called fuse boxes) are fitted either with semi-enclosed (rewirable) fuses (BS 3036) or cartridge fuses (BS 1361). (Fuse wire is commonly supplied to consumers as short lengths of 5 A-, 15 A- and 30 A-rated wire wound on a piece of cardboard.) Modern consumer units usually contain miniature circuit breakers (MCBs) instead of fuses, though cartridge fuses are sometimes still used, as MCBs are prone to nuisance tripping.

Renewable fuses (rewirable or cartridge) allow user replacement, but this can be hazardous as it is easy to put a higher-rated or double fuse element (link or wire) into the holder (*overfusing*), or simply fitting it with copper wire or even a totally different type of conducting object (hairpins, paper clips, nails, etc.) to the existing carrier. Such tampering will not be visible without full inspection of the fuse. Fuse wire was never used in North America for this reason, although renewable fuses continue to be made for distribution boards.

The fuse boxes pictured here are (right) a MEM consumer unit with four rewirable fuse holders (two 30A and two 15A) installed c. 1957 (cover removed); a Wylex standard unit with eight rewirable fuse holders.

The *Wylex standard* consumer unit was very popular in the United Kingdom until the wiring regulations started demanding Residual-Current Devices (RCDs) for sockets that could feasibly supply equipment outside the equipotential zone. The design does not allow for fitting of RCDs or RCBOs. Some Wylex standard models were made with an RCD instead of the main switch, but (for consumer units supplying the entire installation) this is no longer compliant with the wiring regulations as alarm systems should **not** be RCD-protected. There are two styles of fuse base that can be screwed into these units: one designed for rewirable fusewire carriers and one designed for cartridge fuse carriers. Over the years MCBs have been made for both styles of base. In both cases, higher rated carriers had wider pins, so a carrier couldn't be changed for a higher rated one without also changing the base. Cartridge fuse carriers are also now available for DIN-rail enclosures.

In North America, fuses were used in buildings wired before 1960. These "Edison Base" fuses would screw into a fuse socket similar to Edison-base incandescent lamps. Ratings were 5, 10, 15, 20, 25, and 30 amperes. To prevent installation of fuses with an excessive current rating, later fuse boxes included rejection features in the fuseholder socket. Some installations use resettable miniature thermal circuit breakers, which screw into a fuse socket.

One form of fuse box abuse was to put a penny in the socket, which defeated overcurrent protection and resulted in a dangerous condition.

In the 1950s, fuses in new residential or industrial construction for branch circuit protection were superseded by low voltage circuit breakers.

Coordination of fuses in series

Where several fuses are connected in series at the various levels of a power distribution system, it is desirable to blow (clear) only the fuse (or other overcurrent device) electrically closest to the fault. This process is called "coordination" and may require the time-current characteristics of two fuses to be plotted on a common current basis. Fuses are selected so that the minor, branch, fuse disconnects its circuit well before the supplying, major, fuse starts to melt. In this way, only the faulty circuit is interrupted with minimal disturbance to other circuits fed by a common supplying fuse.

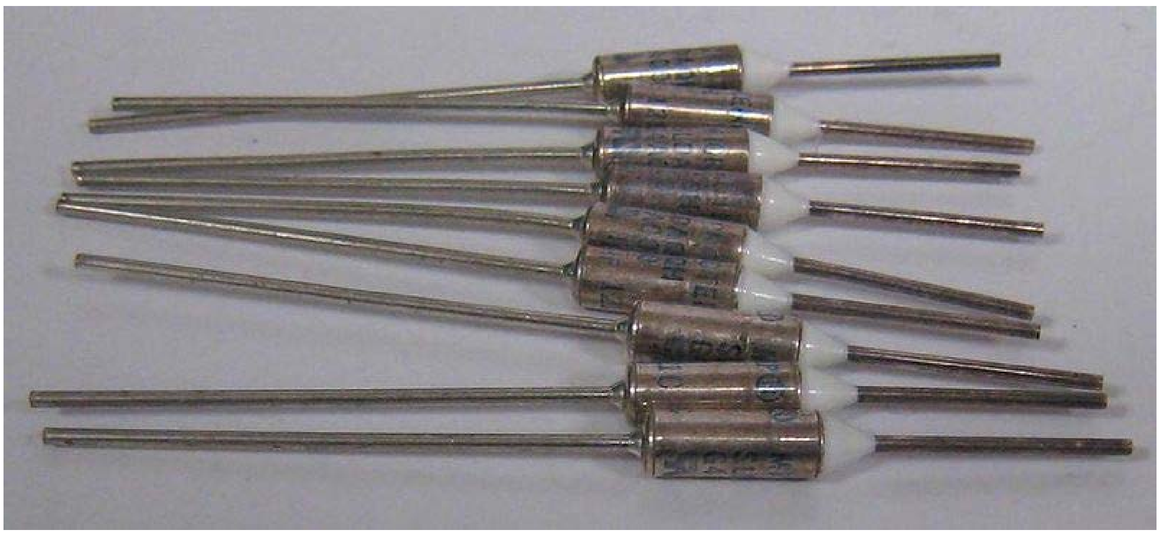
Where the fuses in a system are of similar types, simple rule-of-thumb ratios between ratings of the fuse closest to the load and the next fuse towards the source can be used.

Other fuse types

Resettable fuses

So-called self-resetting fuses use a thermoplastic conductive element known as a Polymeric Positive Temperature Coefficient (or PPTC) thermistor that impedes the circuit during an overcurrent condition (by increasing device resistance). The PPTC thermistor is self-resetting in that when current is removed, the device will cool and revert back to low resistance. These devices are often used in aerospace/nuclear applications where replacement is difficult, or on a computer motherboard so that a shorted mouse or keyboard does not cause motherboard damage.

Thermal fuses



thermal cutoff

A *thermal fuse* is often found in consumer equipment such as coffee makers or hair dryers or transformers powering small consumer electronics devices. They contain a fusible, temperature-sensitive alloy which holds a spring contact mechanism normally closed. When the surrounding temperature gets too high, the alloy melts and allows the spring contact mechanism to break the circuit. The device can be used to prevent a fire in a hair dryer for example, by cutting off the power supply to the heater elements when the air flow is interrupted (e.g., the blower motor stops or the air intake becomes accidentally blocked). Thermal fuses are a 'one shot', non-resettable device which must be replaced once they have been activated (blown).

Chapter-3

Aluminum Wire

Aluminum wire (also spelled **aluminium wire**) is a type of wiring used in houses and power grids.

History

Usage within utilities

Utility companies have used aluminum wire for transmission of electricity within their power grids since the early 1900s. It has advantages over the older copper wire in that it is lighter, more flexible, and less expensive. Aluminum wire in power grid applications was very successful and is still used today.

Increased copper prices

In the mid 1960s when the price of copper spiked, aluminium wire was manufactured in sizes small enough to be used in homes. One thing that was known at the time was that aluminium wire requires a larger wire gauge than copper to carry the same current. For example, a standard 15 A branch circuit wired with No. 14 gauge copper requires No. 12 gauge aluminium.

When first used in branch circuit wiring, aluminium wire was not installed any differently than copper. Typical connections from electrical wire to electrical devices, also called terminals, are usually made by wrapping the wire around screw terminals and tightening the screw. Over time, many of these terminations to aluminium wire began to fail due to improper connection techniques and dissimilar metals. These connection failures generated heat under electrical load and resulted in overheated connections.

In the late 1960s, a device specification known as CU/AL was created that specified standards for devices intended for use with aluminium wire. Because of more rigorous testing, larger screw terminals were designed to hold the wire more suitably. Unfortunately, CU/AL switches and receptacles failed to work well enough with aluminium wire, and a new specification called CO/ALR (meaning copper-aluminium, revised) was created. These devices employ screw terminals that are designed to act as a similar metal to aluminium and to expand at a similar rate. CO/ALR applies only to standard light switches and receptacles; CU/AL is the standard marking for circuit breakers and larger equipment.

ACM wire

The first 8000 series electric conductor alloy, still widely used, was developed and patented in 1972 by Aluminum Company of America (ALCOA). This alloy, along with AA-8030 (patented by Olin in 1973) and AA-8176 (patented by Southwire in 1975 and 1980) perform mechanically like copper. Unlike the AA-1350 series, these 8000 series alloys retain their UTS after the standard current cycle test or the CCST (Current Cycle Submersion Test; both tests are described in ANSI C119.4:2004). Depending on the annealing grade, AA-8176 may elongate up to 30% (according to patent No. RE28419) with less springback effect and possesses a higher Y.S. (19.8 KSI for a coldworked AA-8076 wire, according to patent No. 3697260).

Building wire now uses the new 8000 alloy of aluminum as specified by the National Electrical Code (NEC). Contractors are also using larger sizes of aluminum building wire for low voltage feeders where the savings over copper is significant due the lower weight. Aluminum building wire will have half the weight of copper even though the aluminum conductor must have 50% greater area than copper to carry the same current. The aluminum conductors used for building wire may be compacted in such a way that the overall diameter of the aluminum wire is approximately the same as copper.

This alloy, when used with CO/ALR devices and aluminium-rated twist-on connectors, can be just as safe as copper wiring. However it is extremely rare in branch circuit wiring, and most twist-on connectors in typical branch-circuit sizes, even those designed to connect copper to aluminum wiring, are not rated for aluminum to aluminum connections (an exception is the Marette 63). A home with aluminium wiring installed prior to 1972 probably has the older 1350 series alloy that was designed for power transmission. Due to their undesirable mechanical properties, most 1350 alloys were not suitable for branch wiring.

Problems with aluminium wires

Aluminium wires have been implicated in house fires in which people have been killed. There were several possible reasons why these connections failed. The two main reasons were improper installation and the differences in coefficient of expansion between aluminium wire and the terminations used in the 1960s.

Aluminium oxidation

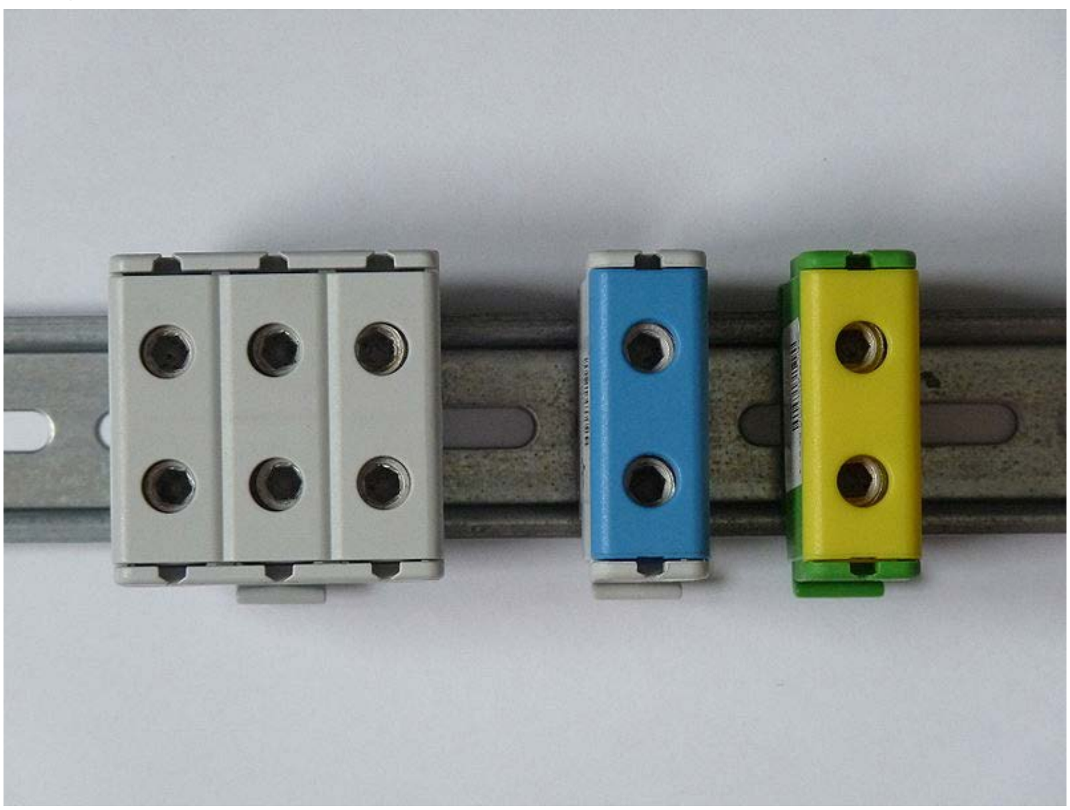
Most metals (with a few exceptions, such as gold) oxidize freely when exposed to air. Aluminium oxide is not an electrical conductor, but rather an electrical insulator. Consequently, the flow of electrons through the oxide layer can be greatly impeded.

However, since the oxide layer is only a few nanometers thick, the added resistance is not noticeable under most conditions. When aluminium wire is terminated properly, the mechanical connection breaks the thin, brittle layer of oxide to form an excellent electrical connection. Unless this connection is loosened, there is no way for oxygen to penetrate the connection point to form further oxide.

Coefficient of expansion

Aluminium's coefficient of expansion varies significantly from the metals common in devices, outlets, switches, and screws that were used before the mid-1970s. Many terminations of aluminium wire installed in the 1960s and 1970s continue to operate with no problems. However, many connections were not made properly when installed. Since the aluminium and steel both expand and contract at different rates under thermal load, these loose connections began to grow progressively looser over time. Likewise, a connection made with too much torque causes damage to the wire. Over time, this cycle results in the connection loosening slightly, overheating, and allowing intermetallic steel/aluminium alloying to occur between the conductor and the screw terminal. This results in a high-resistance junction, leading to additional overheating. Although many believe that oxidation was the issue, studies have shown that oxidation was not significant in these cases.

Joining aluminium and copper wires



Terminals joining aluminium wires to copper wires

Result improperly joined aluminium and copper wires in old USSR apartments, done by qualified electrician

Another issue is the joining of aluminium wire to copper wire. As aluminium and copper are dissimilar metals, galvanic corrosion can occur in the presence of an electrolyte and these connections can become unstable over time. Special connectors have been designed for the purpose of joining aluminium to copper wire, such as the Marrette No. 63 and No. 65 and the Ideal Twister No. 65. These twist-on wire connectors use a special antioxidant paste to prevent corrosion of the connection.

At least one manufacturer, AlumiConn, offers UL/CSA listed lug type connectors similar to those used for larger gauge aluminium-aluminium and aluminium-copper connections for branch circuit size wiring. These would appear to make a more reliable connection on the aluminium wire with its higher coefficient of expansion than wire nut-type connectors. These may have the same problem with enclosure space as the COPALUM system (described under "Upgrading aluminium-wired homes"). A listed connector should always be used for connecting aluminium to copper wire.

Although aluminium wire smaller than 8 AWG is not used in new house wiring, lots of aluminium wires are used all over North America. The larger sizes offer excellent options for terminations, since the most common termination in larger sizes is a dual-rated lug made of an aluminium alloy. Properly terminated aluminium wiring should be regarded as safe, since long-term installations have proven its reliability. Aluminium wire is often used in residential applications for service entrance and large branch circuit loads such as ranges and air-conditioning units.

Hazard insurance

In some states, home hazard insurance will not cover homes with aluminium wiring, and some insurance companies that claim to cover it charge a higher premium than for homes with copper wiring. Reputable and knowledgeable insurers should recognize the difference between AA-8000 series aluminium building wire and that used prior to 1972.

Upgrading aluminium-wired homes

Flat 81 is waiting to be upgraded from Soviet-era aluminium cable to modern copper cable.

There are several "upgrades" that are commonly done to homes with pre-1974 aluminium branch circuit wiring:

- Ensuring that all devices are rated for use with aluminium wire. Many are not, since they do not meet the CO/ALR specification.

- "Pigtailing", which involves splicing a short length of copper to the original aluminium wire for use with devices not CO/ALR rated. Pigtailing can be done with special wire nuts or miniature lug-type connectors. The manufacturer of one brand of wire nuts often used for this purpose has stated that they are not to be used for retrofitting aluminum wiring but only for attaching a limited number of new devices.

- COPALUM, a sophisticated crimping system that creates a cold weld between copper and aluminium wire, and is regarded to be a permanent, maintenance-free repair. These connections are sometimes too large to be installed in existing enclosures. Surface enclosures or larger enclosures may be installed to remedy this problem.

- Completely rewiring the house with copper instead.

The Consumer Product Safety Commission does not recommended the use of pigtailing, as laboratory testing has shown that pigtailing with wire nuts does not effectively mitigate the risk, and in some cases, may *increase* the risk of fire. The only CPSC approved methods of upgrading aluminium wired homes are the COPALUM method, which must be done using special tools and by electricians certified in its use, or by completely rewiring the home with copper.

Chapter-4

Knob and Tube Wiring

Knob and tube wiring in a 1930 home. View looking up at upper wall stud bays and nearby ceiling joists

Knob and tube wiring (sometimes abbreviated **K&T**) was an early standardized method of electrical wiring in buildings, in common use in North America from about 1880 to the 1930s. It consisted of single-insulated copper conductors run within wall or ceiling cavities, passing through joist and stud drill-holes via protective porcelain insulating **tubes**, and supported along their length on nailed-down porcelain **knob** insulators. Where conductors entered a wiring device such as a lamp or switch, or were pulled into a wall, they were protected by flexible cloth insulating sleeving called **loom**. The first insulation was asphalt-saturated cotton cloth, then rubber became common. Wire splices in such installations were twisted together for good mechanical strength, then soldered and wrapped with rubber insulating tape and friction tape (asphalt saturated cloth), or made inside metal junction boxes.

Knob and tube wiring was displaced from interior wiring systems because of the high cost of installation compared with use of power cables, which combined both power conductors of a circuit in one run (and which later included grounding conductors).

New knob and tube installation is permitted in the US only in a few very specific situations listed in the National Electrical Code.

Elements

Ceramic **knobs** were cylindrical and generally nailed directly into the wall studs or floor joists. Most had a circular groove running around their circumference, although some were constructed in two pieces with pass-through grooves on each side of the nail in the middle. A leather washer often cushioned the ceramic, to reduce breakage during installation.

By wrapping electrical wires around the knob, and securing them with **tie wires**, the knob securely and permanently anchored the wire. The knobs separated the wire from potentially combustible framework, facilitated changes in direction, and ensured that wires were not subject to excessive tension. Because the wires were suspended in air, they could dissipate heat well.

Ceramic **tubes** were inserted into holes bored in wall studs or floor joists, and the wires were directed through them. This kept the wires from coming into contact with the wood framing members and from being compressed by the wood as the house settled. Ceramic tubes were sometimes also used when wires crossed over each other, for protection in case the upper wire were to break and fall on the lower conductor.

Ceramic **cleats**, which were block-shaped pieces, served a purpose similar to that of the knobs.

Ceramic **bushings** protected each wire entering a metal device box, when such an enclosure was used.

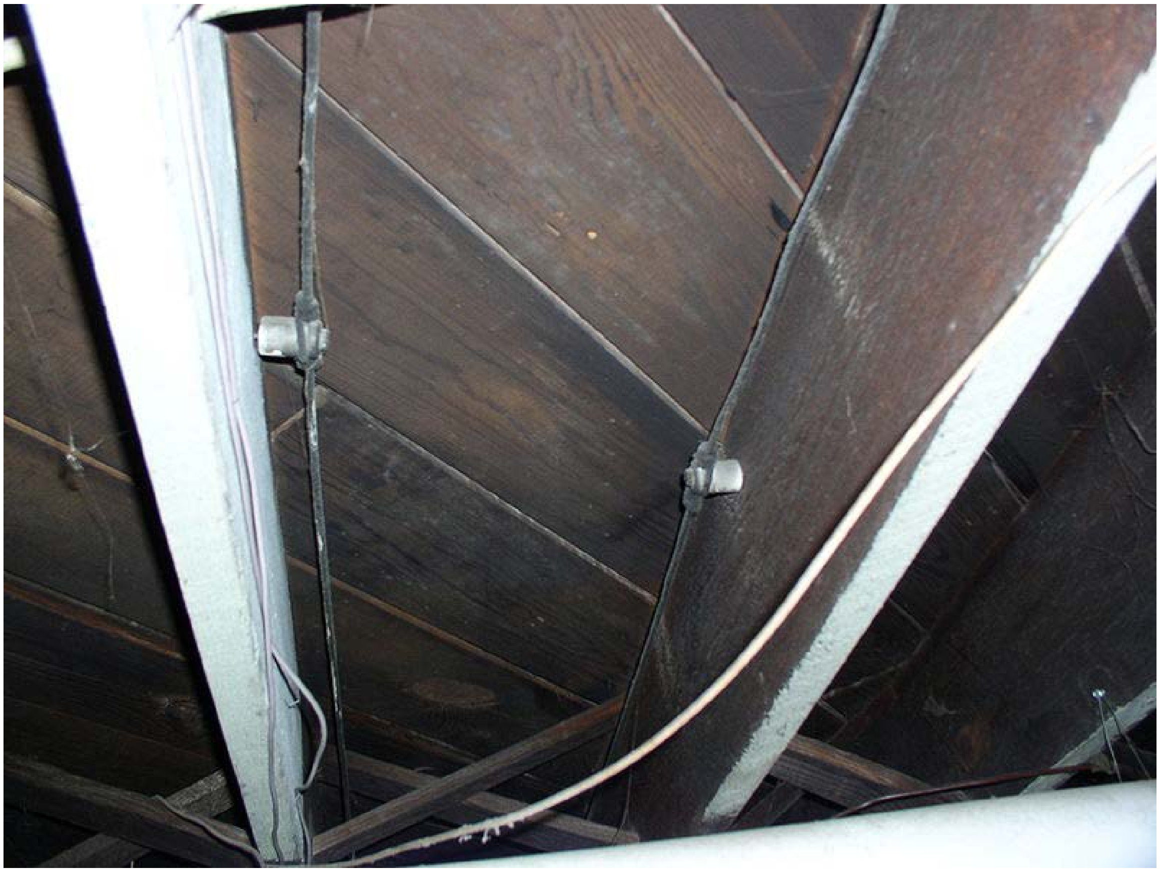
Loom, a woven flexible insulating sleeve, was slipped over insulated wire to provide additional protection whenever a wire passed over or under another wire, when a wire entered a metal device enclosure, and in other situations prescribed by code.

Other ceramic pieces would typically be used as a junction point between the wiring system proper, and the more flexible cloth-clad wiring found in light fixtures or other permanent, hard-wired devices. When a generic power outlet was desired, the wiring could run directly into the junction box through a tube of protective loom.

Wiring devices such as light switches, receptacle outlets, and lamp sockets were either surface-mounted, suspended, or flush-mounted within walls and ceilings. Only in the last case were metal boxes always used to enclose the device.

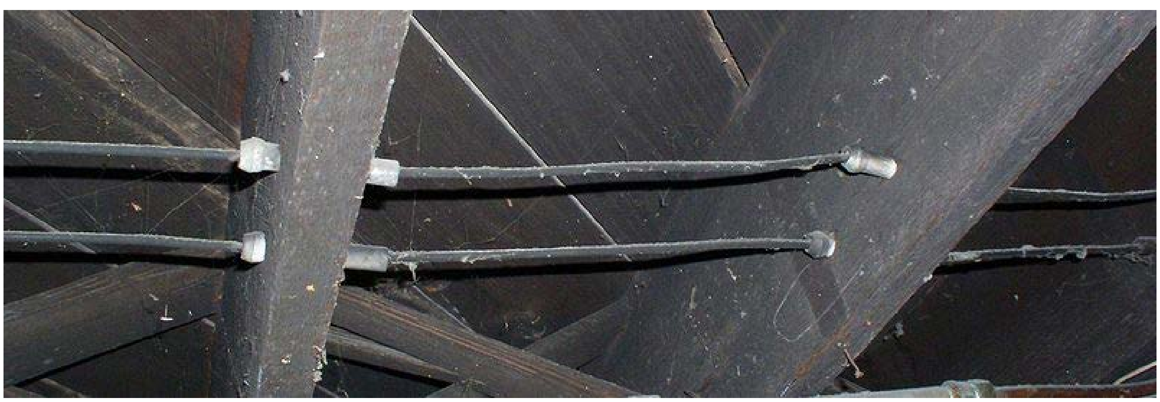
Knob supporting a wire change in direction.

Knob supporting a splice



Knobs supporting long runs of wire

Knobs serving multiple functions



Ceramic tubes protecting wires passing through ceiling joists.

Ceramic junction for suspended light socket. Note deteriorated wire insulation.

Wiring running through tubes, and turning a corner supported by a knob. Notice the direct splice with more modern (1950s-era) NonMetallic sheathed cable. This type of connection is forbidden by NEC electrical code, and other methods should have been used.

Splice with more modern power outlet, a probable code violation as seen here.

Advantages

When originally installed in the early 1900s, K&T wiring was less expensive than other wiring methods. For several decades, electricians could choose between using K&T wiring on one hand, compared to conduit, armored cable, and metal junction boxes on the other. The conduit methods were known to be of better quality, but their cost was significantly higher than that of K&T . In 1909, flexible armored cable cost about twice the cost of K&T, and conduit cost about three times the cost for K&T . Knob and tube wiring persisted since it allowed owners to wire a building for electricity at lower cost.

Modern wiring methods assume two or more load-carrying conductors will lie very near each other, as for instance in standard NM-2 cable. Since the load-carrying wires are in close proximity, when they heat up, the heating is shared across the wires, limiting the overall current load they can support. Since the load-carrying wires in K&T wiring are widely spaced, the wires are capable of carrying higher loads without risk of fire, making it a safe wiring method. It is actually, when used correctly, safer than most modern wiring methods, since the wires are held away from the structural materials by ceramic insulators.

K&T wiring was commonly insulated with cotton cloth and soft rubber, in addition to the porcelain standoffs. Although the actual wire covering may have degraded over the decades, the porcelain standoffs have a nearly unlimited lifespan and will keep any bare wires safely insulated. Today, porcelain standoffs are still commonly used with bare wire electric fencing for livestock, and such porcelain standoffs carry far higher voltage surges without risk of shorting to ground.

In short, K&T wiring which was installed correctly, and not damaged or incorrectly modified since then, is extremely safe when used within the original current-carrying limits.

Disadvantages

Historically, wiring installation requirements were less demanding in the age of knob-and-tube wiring than today. Compared to modern electrical wiring standards, these are the main technical shortcomings of knob-and-tube wiring methods:

- never included a safety grounding conductor
- did not confine switching to the hot conductor (the so-called *Carter system* places loads *across* the common terminals of a three-way switch pair)
- permitted the use of in-line splices in walls without a junction box (and thus exposing a potential fire hazard of an uncontained spark caused by arcing following mechanical failure of the splice).

Knob and tube wiring at a museum display

Over time, the price of electrician labor grew faster than the cost of materials. This removed the price advantage of K&T methods, especially since they required time-consuming skillful soldering of in-line splices and junctions, and careful hand-wrapping of connections in layers of insulating tape.

Knob-and-tube wiring can be made with high current carrying capacity. However, most existing residential knob and tube installations, dating to before 1940, have fewer branch circuits than is desired today. While these installations were adequate for the electrical loads at the time of installation, modern households use a range and intensity of electrical equipment unforeseen at the time. Household power use increased dramatically following World War II due to wide availability of electrical appliances.

Modern home buyers often find that existing K&T systems lack the capacity for today's levels of power use. First-generation wiring systems became susceptible to abuse by homeowners who would replace blown fuses with fuses rated for higher current. This overfusing of the circuits subjects wiring to higher levels of current and risks heat damage.

Knob-and-tube wiring may also be damaged by building renovations . Its cloth and rubber insulation can dry out and turn brittle. It may also be damaged by rodents and careless activities such as hanging objects from wiring running in accessible areas like basements.

For those concerned about stray magnetic fields, knob-and-tube wiring produces a much stronger effect at a given level of current, since the conductors are separated by a greater distance and their fields do not cancel as well as more closely-spaced conductors. According to the theory of magnetic fields, two parallel conductors carrying equal currents in opposite directions form a balanced line, partially cancelling each other's magnetic field at a sufficiently large distance from the pair. As a rule of thumb, if two parallel conductors carrying opposite currents are then separated by 10 times the distance, the stray magnetic field will extend 10 times further than before.

Currently, the United States NEC forbids the use of loose, blown-in, or expanding foam insulation over K&T wiring. This is because K&T is designed to let heat dissipate to the surrounding air. As a result, energy efficiency upgrades that involve insulating previously uninsulated walls usually also require replacement of the wiring in affected homes.

However, California and Washington, as well as possibly other states, have actually reversed the ruling on insulation around K&T. They did not find a single fire that was attributed to K&T, provided that it first passes inspection by an electrician.

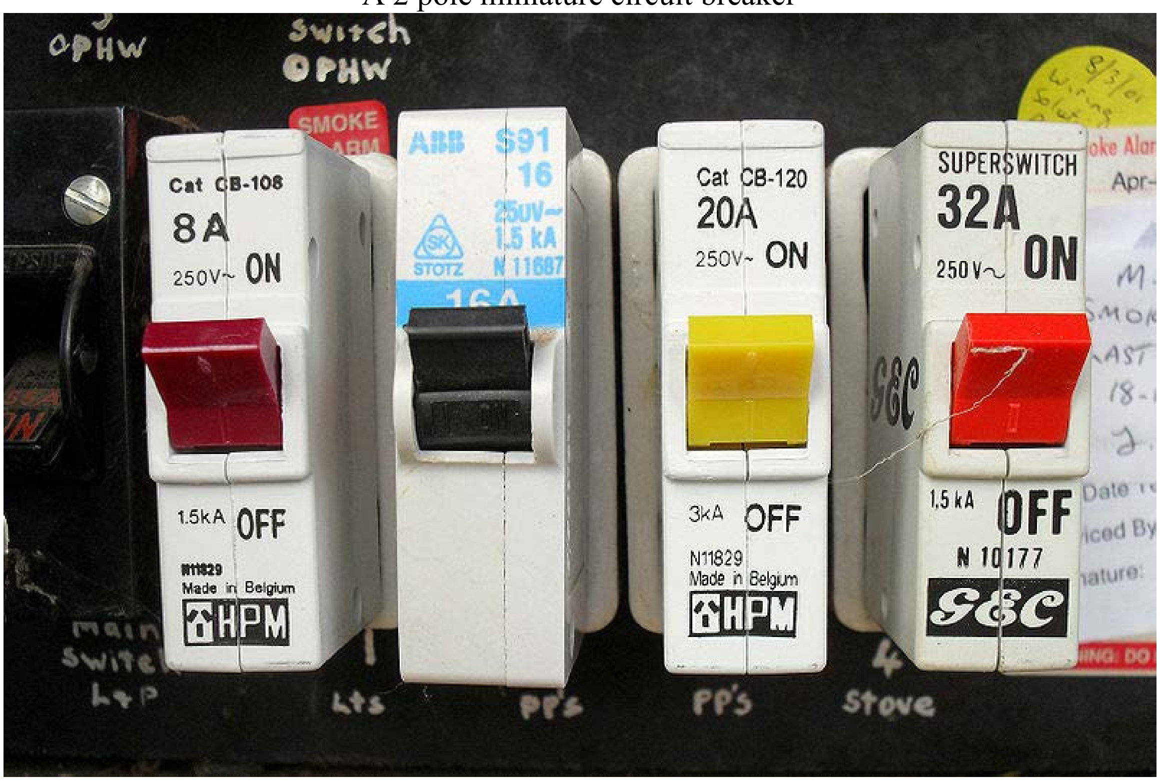
As existing K&T wiring gets older, insurance companies may deny coverage due to a perception of increased risk. Several companies will not write new homeowners policies at all unless all K&T wiring is replaced or an electrician certifies that the wiring is in good condition. Also, many institutional lenders are unwilling to finance a home with limited ampacity (current carrying capacity) service (which, as noted above, often goes hand-in-hand with K&T wiring), unless the electrical service is upgraded.

Chapter-5

Circuit Breaker

An air circuit breaker for low voltage (less than 1000 volts) power distribution switchgear

A 2 pole miniature circuit breaker



Four 1 pole circuit breakers

A **circuit breaker** is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect a fault condition and, by interrupting continuity, to immediately discontinue electrical flow. Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation.

Circuit breakers are made in varying sizes, from small devices that protect an individual household appliance up to large switchgear designed to protect high voltage circuits feeding an entire city.

Origins

An early form of circuit breaker was described by Thomas Alva Edison in an 1879 patent application, although his commercial power distribution system used fuses. Its purpose was to protect lighting circuit wiring from accidental short-circuits and overloads.

Operation

All circuit breakers have common features in their operation, although details vary substantially depending on the voltage class, current rating and type of the circuit breaker.

The circuit breaker must detect a fault condition; in low-voltage circuit breakers this is usually done within the breaker enclosure. Circuit breakers for large currents or high voltages are usually arranged with pilot devices to sense a fault current and to operate the trip opening mechanism. The trip solenoid that releases the latch is usually energized by a separate battery, although some high-voltage circuit breakers are self-contained with current transformers, protection relays, and an internal control power source.

Once a fault is detected, contacts within the circuit breaker must open to interrupt the circuit; some mechanically-stored energy (using something such as springs or compressed air) contained within the breaker is used to separate the contacts, although some of the energy required may be obtained from the fault current itself. Small circuit breakers may be manually operated; larger units have solenoids to trip the mechanism, and electric motors to restore energy to the springs.

The circuit breaker contacts must carry the load current without excessive heating, and must also withstand the heat of the arc produced when interrupting the circuit. Contacts are made of copper or copper alloys, silver alloys, and other materials. Service life of the contacts is limited by the erosion due to interrupting the arc. Miniature and molded case circuit breakers are usually discarded when the contacts are worn, but power circuit breakers and high-voltage circuit breakers have replaceable contacts.

When a current is interrupted, an arc is generated. This arc must be contained, cooled, and extinguished in a controlled way, so that the gap between the contacts can again withstand the voltage in the circuit. Different circuit breakers use vacuum, air, insulating gas, or oil as the medium in which the arc forms. Different techniques are used to extinguish the arc including:

- Lengthening of the arc
- Intensive cooling (in jet chambers)
- Division into partial arcs

- Zero point quenching (Contacts open at the zero current time crossing of the AC waveform, effectively breaking no load current at the time of opening. The zero crossing occurs at twice the line frequency i.e. 100 times per second for 50Hz and 120 times per second for 60Hz AC)
- Connecting capacitors in parallel with contacts in DC circuits

Finally, once the fault condition has been cleared, the contacts must again be closed to restore power to the interrupted circuit.

Arc interruption

Miniature low-voltage circuit breakers use air alone to extinguish the arc. Larger ratings will have metal plates or non-metallic arc chutes to divide and cool the arc. Magnetic blowout coils deflect the arc into the arc chute.

In larger ratings, oil circuit breakers rely upon vaporization of some of the oil to blast a jet of oil through the arc.

Gas (usually sulfur hexafluoride) circuit breakers sometimes stretch the arc using a magnetic field, and then rely upon the dielectric strength of the sulfur hexafluoride (SF_6) to quench the stretched arc.

Vacuum circuit breakers have minimal arcing (as there is nothing to ionize other than the contact material), so the arc quenches when it is stretched a very small amount (<23 mm). Vacuum circuit breakers are frequently used in modern medium-voltage switchgear to 35,000 volts.

Air circuit breakers may use compressed air to blow out the arc, or alternatively, the contacts are rapidly swung into a small sealed chamber, the escaping of the displaced air thus blowing out the arc.

Circuit breakers are usually able to terminate all current very quickly: typically the arc is extinguished between 30 ms and 150 ms after the mechanism has been tripped, depending upon age and construction of the device.

Short-circuit current

Circuit breakers are rated both by the normal current that are expected to carry, and the maximum short-circuit current that they can safely interrupt.

Under short-circuit conditions, a current many times greater than normal can exist. When electrical contacts open to interrupt a large current, there is a tendency for an arc to form between the opened contacts, which would allow the current to continue. This condition can create conductive ionized gasses and molten or vaporized metal which can cause further continuation of the arc, or creation of additional short circuits, potentially resulting in the explosion of the circuit breaker and the equipment that it is installed in.

Therefore, circuit breakers must incorporate various features to divide and extinguish the arc.

In air-insulated and miniature breakers an *arc chute* structure consisting (often) of metal plates or ceramic ridges cools the arc, and magnetic blowout coils deflect the arc into the arc chute. Larger circuit breakers such as those used in electrical power distribution may use vacuum, an inert gas such as sulphur hexafluoride or have contacts immersed in oil to suppress the arc.

The maximum short-circuit current that a breaker can interrupt is determined by testing. Application of a breaker in a circuit with a prospective short-circuit current higher than the breaker's interrupting capacity rating may result in failure of the breaker to safely interrupt a fault. In a worst-case scenario the breaker may successfully interrupt the fault, only to explode when reset.

Miniature circuit breakers used to protect control circuits or small appliances may not have sufficient interrupting capacity to use at a panelboard; these circuit breakers are called "supplemental circuit protectors" to distinguish them from distribution-type circuit breakers.

Standard current ratings

International Standard IEC 60898-1 and European Standard EN 60898-1 define the *rated current* I_n of a circuit breaker for low voltage distribution applications as the current that the breaker is designed to carry continuously (at an ambient air temperature of 30 °C). The commonly-available preferred values for the rated current are 6 A, 10 A, 13 A, 16 A, 20 A, 25 A, 32 A, 40 A, 50 A, 63 A, 80 A and 100 A (Renard series, slightly modified to include current limit of British BS 1363 sockets). The circuit breaker is labeled with the rated current in amperes, but without the unit symbol "A". Instead, the ampere figure is preceded by a letter "B", "C" or "D" that indicates the *instantaneous tripping current*, that is the minimum value of current that causes the circuit-breaker to trip without intentional time delay (i.e., in less than 100 ms), expressed in terms of I_n:

Type	**Instantaneous tripping current**
B	above 3 I_n up to and including 5 I_n
C	above 5 I_n up to and including 10 I_n
D	above 10 I_n up to and including 20 I_n
K	above 8 I_n up to and including 12 I_n For the protection of loads that cause frequent short duration (approximately 400 ms to 2 s) current peaks in normal operation.
Z	above 2 I_n up to and including 3 I_n for periods in the order of tens of seconds. For the protection of loads such as semiconductor devices or measuring circuits using current transformers.

Types of circuit breaker

Front panel of a 1250 A air circuit breaker manufactured by ABB. This low voltage power circuit breaker can be withdrawn from its housing for servicing. Trip characteristics are configurable via DIP switches on the front panel.

Many different classifications of circuit breakers can be made, based on their features such as voltage class, construction type, interrupting type, and structural features.

Low voltage circuit breakers

Low voltage (less than 1000 V_{AC}) types are common in domestic, commercial and industrial application, and include:

- MCB (Miniature Circuit Breaker)—rated current not more than 100 A. Trip characteristics normally not adjustable. Thermal or thermal-magnetic operation. Breakers illustrated above are in this category.

- MCCB (Molded Case Circuit Breaker)—rated current up to 2500 A. Thermal or thermal-magnetic operation. Trip current may be adjustable in larger ratings.

- Low voltage power circuit breakers can be mounted in multi-tiers in LV switchboards or switchgear cabinets.

The characteristics of LV circuit breakers are given by international standards such as IEC 947. These circuit breakers are often installed in draw-out enclosures that allow removal and interchange without dismantling the switchgear.

Large low-voltage molded case and power circuit breakers may have electrical motor operators, allowing them to be tripped (opened) and closed under remote control. These may form part of an automatic transfer switch system for standby power.

Low-voltage circuit breakers are also made for direct-current (DC) applications, for example DC supplied for subway lines. Special breakers are required for direct current because the arc does not have a natural tendency to go out on each half cycle as for alternating current. A direct current circuit breaker will have blow-out coils which generate a magnetic field that rapidly stretches the arc when interrupting direct current.

Small circuit breakers are either installed directly in equipment, or are arranged in a breaker panel.

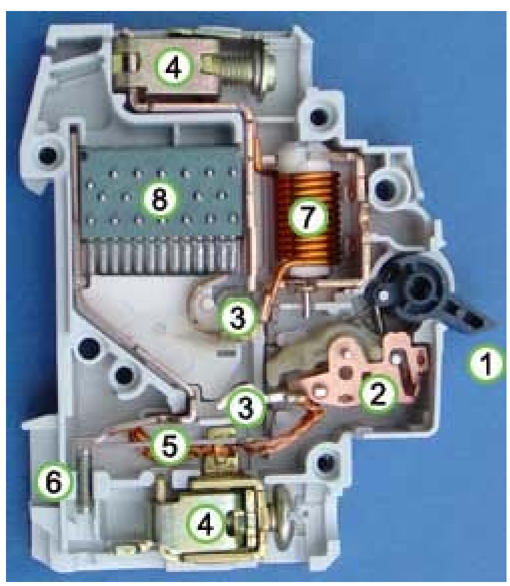


Photo of inside of a circuit breaker

The 10 ampere DIN rail-mounted thermal-magnetic miniature circuit breaker is the most common style in modern domestic consumer units and commercial electrical distribution boards throughout Europe. The design includes the following components:

1. Actuator lever - used to manually trip and reset the circuit breaker. Also indicates the status of the circuit breaker (On or Off/tripped). Most breakers are designed so they can still trip even if the lever is held or locked in the "on" position. This is sometimes referred to as "free trip" or "positive trip" operation.
2. Actuator mechanism - forces the contacts together or apart.
3. Contacts - Allow current when touching and break the current when moved apart.
4. Terminals
5. Bimetallic strip.
6. Calibration screw - allows the manufacturer to precisely adjust the trip current of the device after assembly.
7. Solenoid
8. Arc divider/extinguisher

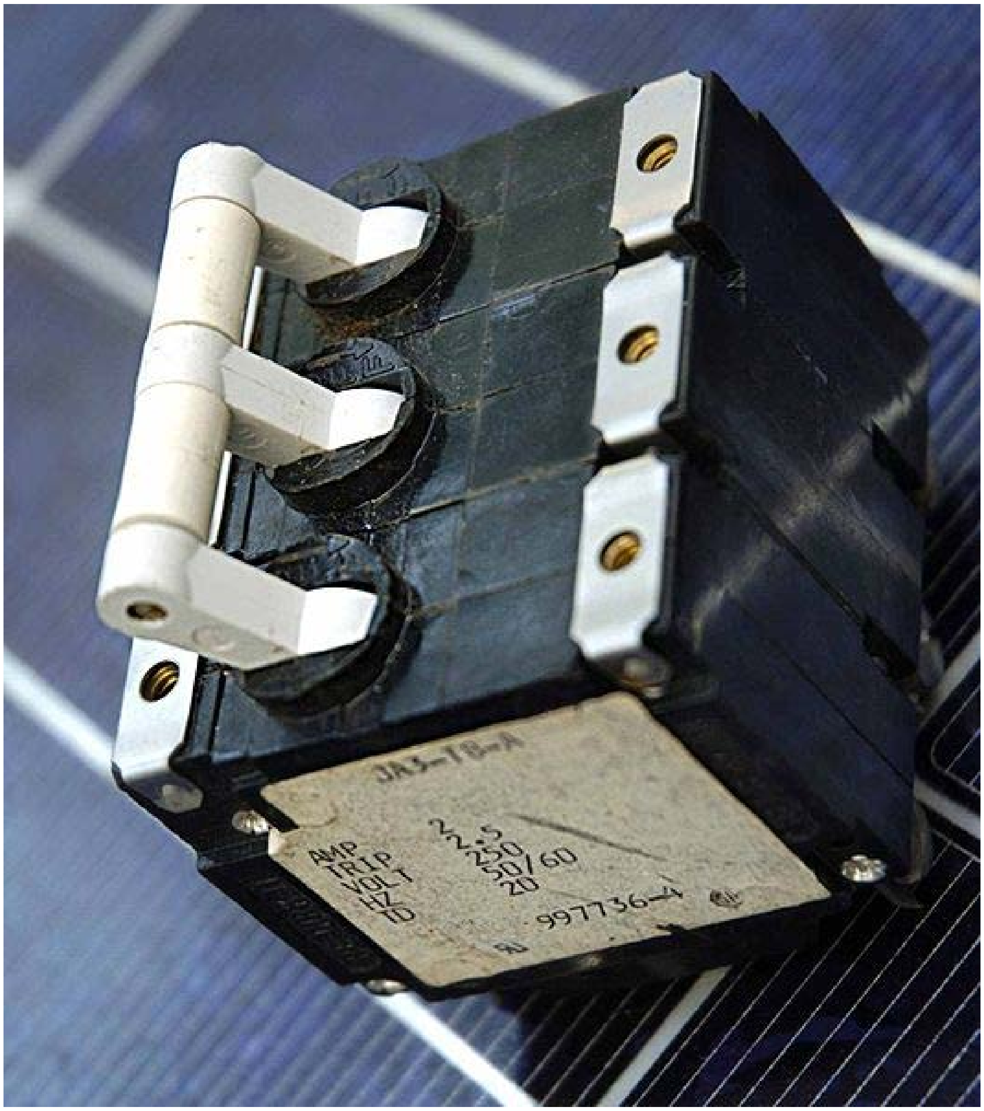
Magnetic circuit breaker

Magnetic circuit breakers use a solenoid (electromagnet) whose pulling force increases with the current. Certain designs utilize electromagnetic forces in addition to those of the solenoid. The circuit breaker contacts are held closed by a latch. As the current in the solenoid increases beyond the rating of the circuit breaker, the solenoid's pull releases the latch which then allows the contacts to open by spring action. Some types of magnetic breakers incorporate a hydraulic time delay feature using a viscous fluid. The core is restrained by a spring until the current exceeds the breaker rating. During an overload, the speed of the solenoid motion is restricted by the fluid. The delay permits brief current surges beyond normal running current for motor starting, energizing equipment, etc. Short circuit currents provide sufficient solenoid force to release the latch regardless of core position thus bypassing the delay feature. Ambient temperature affects the time delay but does not affect the current rating of a magnetic breaker.

Thermal magnetic circuit breaker

Thermal magnetic circuit breakers, which are the type found in most distribution boards, incorporate both techniques with the electromagnet responding instantaneously to large surges in current (short circuits) and the bimetallic strip responding to less extreme but longer-term over-current conditions.

Common trip breakers



Three pole common trip breaker for supplying a three-phase device. This breaker has a 2 A rating

When supplying a branch circuit with more than one live conductor, each live conductor must be protected by a breaker pole. To ensure that all live conductors are interrupted when any pole trips, a "common trip" breaker must be used. These may either contain two or three tripping mechanisms within one case, or for small breakers, may externally tie the poles together via their operating handles. Two pole common trip breakers are common on 120/240 volt systems where 240 volt loads (including major appliances or further distribution boards) span the two live wires. Three-pole common trip breakers are typically used to supply three-phase electric power to large motors or further distribution boards.

Two and four pole breakers are used when there is a need to disconnect the neutral wire, to be sure that no current can flow back through the neutral wire from other loads connected to the same network when people need to touch the wires for maintenance. Separate circuit breakers must never be used for disconnecting live and neutral, because if the neutral gets disconnected while the live conductor stays connected, a dangerous condition arises: the circuit will appear de-energized (appliances will not work), but wires will stay live and RCDs will not trip if someone touches the live wire (because RCDs need power to trip). This is why only common trip breakers must be used when switching of the neutral wire is needed.

Medium-voltage circuit breakers

Medium-voltage circuit breakers rated between 1 and 72 kV may be assembled into metal-enclosed switchgear line ups for indoor use, or may be individual components installed outdoors in a substation. Air-break circuit breakers replaced oil-filled units for indoor applications, but are now themselves being replaced by vacuum circuit breakers (up to about 35 kV). Like the high voltage circuit breakers described below, these are also operated by current sensing protective relays operated through current transformers. The characteristics of MV breakers are given by international standards such as IEC 62271. Medium-voltage circuit breakers nearly always use separate current sensors and protective relays, instead of relying on built-in thermal or magnetic overcurrent sensors.

Medium-voltage circuit breakers can be classified by the medium used to extinguish the arc:

- Vacuum circuit breaker—With rated current up to 3000 A, these breakers interrupt the current by creating and extinguishing the arc in a vacuum container. These are generally applied for voltages up to about 35,000 V, which corresponds roughly to the medium-voltage range of power systems. Vacuum circuit breakers tend to have longer life expectancies between overhaul than do air circuit breakers.

- Air circuit breaker—Rated current up to 10,000 A. Trip characteristics are often fully adjustable including configurable trip thresholds and delays. Usually electronically controlled, though some models are microprocessor controlled via an integral electronic trip unit. Often used for main power distribution in large industrial plant, where the breakers are arranged in draw-out enclosures for ease of maintenance.

- SF_6 circuit breakers extinguish the arc in a chamber filled with sulfur hexafluoride gas.

Medium-voltage circuit breakers may be connected into the circuit by bolted connections to bus bars or wires, especially in outdoor switchyards. Medium-voltage circuit breakers in switchgear line-ups are often built with draw-out construction, allowing the breaker to be removed without disturbing the power circuit connections, using a motor-operated or hand-cranked mechanism to separate the breaker from its enclosure.

High-voltage circuit breakers

Russian 110 kV oil circuit breaker

115 kV bulk oil circuit breaker

400 kV SF_6 live tank circuit breakers

Electrical power transmission networks are protected and controlled by high-voltage breakers. The definition of *high voltage* varies but in power transmission work is usually thought to be 72.5 kV or higher, according to a recent definition by the International Electrotechnical Commission (IEC). High-voltage breakers are nearly always solenoid-operated, with current sensing protective relays operated through current transformers. In substations the protective relay scheme can be complex, protecting equipment and buses from various types of overload or ground/earth fault.

High-voltage breakers are broadly classified by the medium used to extinguish the arc.

- Bulk oil
- Minimum oil
- Air blast
- Vacuum
- SF_6

Some of the manufacturers are ABB, GE (General Electric) , Tavrida Electric, Alstom, Mitsubishi Electric, Pennsylvania Breaker, Siemens, Toshiba, Končar HVS, BHEL, CGL, Square D (Schneider Electric).

Due to environmental and cost concerns over insulating oil spills, most new breakers use SF_6 gas to quench the arc.

Circuit breakers can be classified as *live tank*, where the enclosure that contains the breaking mechanism is at line potential, or *dead tank* with the enclosure at earth potential. High-voltage AC circuit breakers are routinely available with ratings up to 765 kV. 1200KV breakers are likely to come into market very soon.

High-voltage circuit breakers used on transmission systems may be arranged to allow a single pole of a three-phase line to trip, instead of tripping all three poles; for some classes of faults this improves the system stability and availability.

Sulfur hexafluoride (SF_6) high-voltage circuit-breakers

A sulfur hexafluoride circuit breaker uses contacts surrounded by sulfur hexafluoride gas to quench the arc. They are most often used for transmission-level voltages and may be incorporated into compact gas-insulated switchgear. In cold climates, supplemental heating or de-rating of the circuit breakers may be required due to liquefaction of the SF_6 gas.

Other breakers

The following types are described in separate articles.

- Breakers for protections against earth faults too small to trip an over-current device:
    - Residual current breaker with over-current protection (RCBO) — combines the functions of an RCD and an MCB in one package. In the United States and Canada, panel-mounted devices that combine ground (earth) fault detection and over-current protection are called Ground Fault Circuit Interrupter (GFCI) breakers; a wall mounted outlet device providing ground fault detection only is called a GFI.
    - Earth leakage circuit breaker (ELCB) — This detects earth current directly rather than detecting imbalance. They are no longer seen in new installations for various reasons.
- Autorecloser — A type of circuit breaker which closes again after a delay. These are used on overhead power distribution systems, to prevent short duration faults from causing sustained outages.
- Polyswitch (polyfuse) — A small device commonly described as an automatically resetting fuse rather than a circuit breaker.

Chapter-6

Home Wiring

Home wiring is wiring in domestic use such as houses and gardens.

Overview

The evolution of home wiring can be said to have started when electric lights and telephone where first installed in homes towards the end of the 19th century. Only towards the end of the 20th century have we seen the explosion of services and technologies that have increased the amount of cabling in the home. In many countries around the world any new dwelling must include what are referred to as essential services these are typically:

1. Water
2. Sewage
3. Electricity

Whilst these services are essential most new homes will also have provision for Telephone, Internet access, Security, Pay TV to name a few.

When a home is built plumbing is installed to distribute the water and sewage to the location where it is needed in the home. At the same time electrical cabling is also installed to provide light and power throughout the home. Now in addition to this you also need to have an infrastructure to support all the new services now available to a modern home.

Home wiring elements

The elements that make up home wiring are:

- Power point (also known as Wall outlets)
- Light fittings
- Telephone
- Data
- Free to air TV

- Pay TV
- IPTV
- Home theater
- Distributed audio
- Security monitoring
- Security CCTV
- Automation
- Energy management

Service connection

Here we, looks at the services that need connection and what are the typical connection types required. the services that need connectivity from an outside party are:

- Electricity supply
- Telephony
- Internet
- Free to air TV
- Pay TV
- IPTV
- Audio
- Security

All of the above services have to have some way of being connected to your home and somewhere to house any connection equipment. A simple example is the electricity supply as in most cases it is a cable from the street pole or underground supply that runs into your switch board. Your switch board is typically a metal box mounted on the outside wall of your house. In may new homes the location of the electrical switchboard is on the outside of the external wall of the garage.

How services are connected will vary depending on the service provider and location of the home.

looking at each element

Power point

Power points need to be installed throughout the house in locations where power will be required. In most countries the installation must be done in compliance with standards and by a licensed or qualified electrician.

Power points are typically located where there will be an appliance installed such as, telephone, computers, television, home theater, security system, CCTV system.

Fore more details on electrical wiring practices you can read Electrical wiring

Light fittings

This is even more of a challenge than the power point as the number of light fitting does depend on the type of light fitting. So for this reason we cannot give you much as it depends in the function of the room. So work out the function or functions of each room and identify where the you need to install various light fittings and which group of light you would need on depending on the use of the room, then you can determine how much cable and where. In most countries the installation must be done in compliance with standards and by a licensed or qualified electrician.

Fore more details on electrical wiring practices you can read Electrical wiring

Telephone

To allow for connection of telephone points you need to have cabling installed from the point where the telephone company has installed their cabling to where you want the phone points. In many of the new homes this is typically located near the electrical switch board but not always. You need to identify where you want the phone system or handset physically connected. Probably the best location is in the kitchen and possibly the study. The telephone cabling typically uses two pair twisted cable terminated onto a telephone plug. The cabling is typically installed as a daisy chain starting from the point where the telephone company connects to the home or start wired if it is more practical.

Data

Data wiring has two components, these are:

1. Data service delivery
2. Data network cable

Data service delivery

The three most common ways data services are delivered to the home:

1. ADSL service on the back of the telephone cabling
2. Cable Modem
3. Fiber

ADSL service

ADSL services are typically delivered using the telephone cabling. So wherever you have a telephone point you can install your ADSL modem. When you have an ADSL modem you also need to install a filter at every location where you have a phone plugged in. If you want to install the ADSL modem in a room where you don't have any phone point you will need to install a phone point by extending the phone cabling from the nearest existing phone point.

Cable Modem cable modems are typically installed in location where there is an existing Pay TV service outlet. The installation requires the installation of a Pay TV outlet (F connector) at which point your connect the cable modem.

Fiber Fiber is the least common but it is growing in numbers. If the home has fiber to it then the fiber terminates on what is known as an Optical Network Termination unit (ONT) and it has a data port on it. Cabling from the street to the point where the ONT is installed is fiber and is typically installed by the service provider.

In all three cases the modem supplied or the ONT will have a data port which is an RJ45 socket and this is the port that needs to be connected to the devices you need to connect to the internet. This is the data network cabling or LAN cabling.

Data Network cabling

To extend the data service from the data port on the ADSL modem, Cable Modem or ONT to your networking devices (PC, printers, TV etc.) you need to install data cabling also referred to as LAN cabling. The cabling used for data networking is similar to the phone cabling as it is twisted pair but of a much higher quality. The cable is known as Cat 5 or Cat 6 where Cat stands for Category. What you need to do is decide where are you networking devices and install cabling from the location where the data modem is located to where you have your PCs or TVs that need to connect to the internet. The cabling must be installed as a start wired configuration, that is the cabling runs from the point next to the modem uninterrupted up to where you install the outlet next to the device that needs to be connected to the internet. So unlike the phone wiring where you could wire from one outlet to the next, here each outlet is wired individually back to the location next to the modem. Therefore next to the modem you will have what is known as a patch panel. Note, if all you need to plug into the modem is one computer then you can simply buy a Ethernet cable of the desired length and connected to between the modem and the PC.

Free to air TV

Cabling for free to air TV requires the following:

1. An antenna
2. Coaxial cable
3. TV outlets

There are a range of television antennas for a range of different locations, it is best to consult with your local supplier as to which one is best in you situation. The antenna is typically mounted external to the building most commonly on the roof. From the antenna you need to run a coaxial cable from the antenna to the location where the television is located. today the most common type of cable used for this purpose is RG-6 Tri-shield or quad-shield cable. The cable is terminated on a television outlets. the television outlets are typically an F connector mounted on a face plate.

In cases where you need multiple television outlets then you run the cable from the antenna to an RF splitter. The RF splitter typically has one input for the cable from the Antenna and two or more outlets depending on the splitter. From the splitter you then run a coaxial cable to each outlet you are installing.

'***Additional notes'***

1. On RF splitters, there are a few different types depending on the application. They range from very basic splitters to active splitters when you install many TV outlets throughout the home.
2. Whilst most TV outlets use the F connector the Television or digital set top box usually come with a connector known as Belling Lee so the cable used to connect from the TV outlet to the television will need to have an F connector in one end and a Belling Lee connector at the other end.

Pay TV

The distribution of pay TV through the home uses the same type of cabling used for Free to Air TV with some variations. The variations are:

1. There is no antenna as there is either a satellite dish or a cable from the street.
2. The cabling must be RG-6 quad shield
3. You may be required to used the cable and cabling connectors approved by your pay TV provider
4. A Pay TV Set Top Box needs to be installed at each television where you want to have access to Pay TV services.

In most cases the Pay TV company will supply and install the satellite dish or cable from the street and the cabling to the various location where your televisions are. Whilst you can pre-wire for it if you do it must comply with the requirements detailed by the Pay TV company you choose.

In many cases Pay TV services also require a telephone point so you can access movies on demand, so if you have a Pay TV point you also need a phone plug.

IPTV

IPTVis television delivered to your home via the internet. So on any device you want to watch IPTV on must be connected to the internet. To be connected to the internet it must be connected to your data network.

Home theater

Home theater is very difficult to pre wire for as you need to know what home theater system you are installing as there are two main types to consider 5.1 and 7.1 and that is only the beginning. then you need to look at what extras the equipment you are using requires in addition to the basic 5.1 or 7.1.

1. Two front speakers one on the left of the screen and one on the right of the screen,
2. One front speaker cable just above or below the screen which is the middle front
3. Two rear speakers one on the left and one of the right in line with front left and right speaker locations
4. The sub-woofer which can be anywhere in the room acoustically but must be relatively close to the active equipment the amplifier or surround sound receiver.

The cable you need to install for all speakers except the sub-woofer is known as speaker cable which is figure eight multi-strand copper cable. If the installation you are doing is permanent then go for good quality cable as it will be in the walls for a long time and you don't want to replace it.

Cabling for the sub-woofer is typically a single shielded cable terminated on an RCA connector.

if you happen to have a 7.1 system then you also need to cable for speakers that are installed between the front and back speakers.

The simplest installation of a home theater system is by using a large flat screen TV as the source for the video and have all the home theater equipment installed next to the TV screen. If on the other hand you are planning on installing a rear projection unit and a screen then you need to think how to get the video signal from your home theater equipment to the projector. The cabling used for this is known as an HDMI cable and there are limits to how long this cable can be.

so the starting point for the cabling of a home theater system is, identify the equipment you are going to use, decide if you are going to use a flat screen TV or a rear projection unit and then draw a diagram with all the cable you need as you cannot leave any out. Once you have done this can you then run the cable in. Warning, you also need next to all main equipment a power point or power outlets and telecommunications, data, free to air and pay TV outlets. The sub-woofers are commonly active speakers and are required to be plugged into the mains as well.

Distributed audio

Distributed audio refers to having the ability to have music throughout the house, where the music sources are all centralized. In every room and hallways you have a pair of speakers and you can select to have all speakers play the same music throughout the house or have different music in different location or zones as they are referred to. You can also remotely control the music sources and volume throughout the house. There are a wide range of distributed audio systems in the market and therefore the cabling you need depends on the system you are installing.

When wiring a distributed audio system the first step is CHOOSE YOUR EQUIPMENT" and check what wiring is required by the equipment you have purchased. In summary there are a few ways to wire up the system:

1. Spear cabling is installed from the central equipment to the speaker location
2. Cat 5 or Cat 6 cable is installed from the Central equipment to the speaker location
3. Cat 5 or Cat 6 cable is installed to each room where you want the distributed audio and in each room you have an amplifier and speaker locally installed

So the first step when wiring your distributed audio systems is CHOOSE YOUR EQUIPMENT then read the manual and find out what cabling you need. Then you can install the cabling required. If you are thinking how do I choose my system, look for the functionality you want.

Security monitoring

Security monitoring (burglar alarm) systems contain basic components of:

1. Code pad
2. Siren and strobe light
3. Motion detectors
4. Main panel

and may have additional components.

Cabling for traditional equipment

Code pad The code pad is typically found inside the font door or any other access door. The code pad is used to alarm the system on departure and disarm the system on entry. The cabling required is 6 core multi strand copper cable.

Siren and strobe light The siren and strobe light are typically installed outside the front of the house where it can be seen from the street and is protected from the weather. The cabling required is a 6 core multi strand copper cable.

Motion detectors The motion detectors installed in locations throughout the house were any intrusion into the home can be detected. The best way to think of this is, which are the rooms that have direct access from the outside, where can I place a detector to pick up any intrusion. On solution is to place a motion sensor in each room, as this can be expensive an alternate is place one immediately outside in the common corridor to all rooms. The cabling required is a 6 core multi strand copper cable.

Main equipment The main equipment is typically installed in a location that is not easily accessible such as a cupboard or sub floor area where in the event of an intrusion the person(s) cannot easily find it and interfere with the unit. The main unit requires a power point installed next to it for main power. It also needs a connection to the telephone line servicing the home so in situations where a back to base service is required it can be connected to the phone line. Note the connection of the security system to the phone line requires a wiring configuration that allows the security system to disconnect all phones in the home when it needs to connect to the monitoring center. This is critical, if the wiring is not correct the system may not communicate back to base when an intrusion is detected.

All cabling from the code pad, siren and strobe light and motion detectors need to be run out from the main equipment. It is also recommended that the cabling to each code pad, motion detector are individual runs from the main equipment to the device. By having each device individually connected to the main equipment is facilitates maintenance and allows for more effective monitoring.

Cabling for IP Based systems

Like the traditional equipment the IP based systems require as a minimum:

1. Code pad
2. Siren and strobe light
3. Motion detectors
4. Main equipment

The difference here is the cabling to connect the main equipment is either Cat 5 or Cat 6 and it is installed as part of the data cabling of the home.

Security CCTV

This is becoming more sought after in private home as an additional level of security. The wiring required to install a CCTV system is Data cabling, refer to the section here titled "Data network cabling". What you need to determine is where do you want to install the CCTV cameras and wherever you want the camera you need to install a data outlet. The location where you install the cameras will vary from home to home but typically they are installed so you can see anyone approaching any of the entry areas of the home.

The advantage of an IP bases system is the flexibility to add devises at a later stage. That is you can cable to as many locations as you want and have it terminate on a data outlet near where you may be planning to add devices at a later stage. Adding the device is as simple as plugin it into the outlet and configuring the device.

Automation

Automation refers to the ability to be able to control a range of devices in the home ranging from lights to curtains. The most common example of automation are referred to as Lighting control systems. Lighting control system need to be installed by a qualified professional as the cabling is only one element but without the equipment and programming you cannot even turn a light on. The cabling required when installing an automation system can be dived into two parts:

1. Electrical
2. Data Bus

Electrical This is cabling installed from the electrical switchboard to the light fitting or any other device that is to be controlled by the automation system. For example if you have four down lights in a room and you wish to control each light individually, then each light will be wired back using electrical cabling back to the electrical switchboard. This means you will have four electrical cables installed from the electrical switchboard to the location where the light fittings will be installed. Each cable will be a three core active, neutral and earth cable. If in that room you also have a free standing lamp plugged into a power point and you also want to control this from your automation system, you will need to have that power point individually wired back to the electrical switchboard. So if you want to individually control every light fitting and every power point or power outlets then each one of these devices must be individually wired back to the electrical switchboard. As you can see this start to become quite a lot of electrical cabling so planning is essential.

Note, when you are using an automation system, there is no need to install any electrical cabling to the light switches. In a traditional electrical installation without automation the lights in a room would be wired back to the light switch which in turn would be wired back to the switchboard or some similar arrangement, so keep reading.

Data Bus Once you have installed the electrical cabling you need to install the data bus cable from the electrical switchboard to every location you want to have a light switch or control panel installed (control panel is like the code pad on a security system or touch screen that gives you access to various control functions). The most common cable used for this is a Category 5 cable. The cable can be installed in either a daisy chain or star wired configuration. The importance is to minimize the cable length to avoid an communications problem on the bus.

Energy management

Energy management is a new and upcoming topic in particular at the home. Older systems tended to be cable however all new systems use one of a variety of wireless solutios. This enables them to be effectively retrofitted into existing homes with the minimum of distruption.

If a cabled system is selected cabling needs to be deployed to the major appliances in the home. The cabling is installed as part of the data cabling as per detailed here in the section titled "Data Network Cabling". In addition to a cable being installed to every major appliance you also need to install a data cable near the electricity meter.

The major appliances being considered at this stage are:

1. Electric hot water system
2. Air Conditioning
3. Pool pump
4. Fridge / freezer

Should a wireless system be selected the need for such disrution is removed. Smart plugs or switches can be used to connected the major appliances to the electricity supply and the home energy management system will wirelessly control them.

Who can do the work

Whilst the rules of who can do what in the area of cabling varies from country to country you should not attempt any cabling unless you have taken the time to learn how to do it properly. Cabling is not a difficult job at face value but if not done properly it can be the cause of countless difficult problems to rectify and can lead to serious and potentially fatal installations.

The first thing to consider when wanting to get some cable installed is find out what are the local regulations and licencing requirements. At a high level many countries clearly delineate between the installation of hazardous services from others based on the voltage used. Voltages typically found in a home can be divided into two categories:

1. Extra low voltage (ELV)
2. Low voltage (LV)

whilst the voltage range may vary slightly between some standards for what is an ELV or LV voltage the rationale behind this categorization is the potential threat they pose. ELV is considered low risk whilst LV is considered to be high risk which can cause severe injury including death.

Below are the cabling system and associated voltage so you can judge for yourself where it is best to get someone that knows what they are doing to do the work.

Low Voltage	**Extra Low Voltage**
Power point	
Light fittings	
	Telephone
	Data
	Free to air TV
	Pay TV
	IPTV
	Home theater
	Distributed audio
	Security monitoring

	Security CCTV
Automation	Automation
	Energy management

Chapter-7

Distribution Board

A fairly standard American circuit breaker panel manufactured by General Electric and using *interchangeable* circuit breakers

A **distribution board** (or **panelboard**) is a component of an electricity supply system which divides an electrical power feed into subsidiary circuits, while providing a protective fuse or circuit breaker for each circuit, in a common enclosure. Normally, a main switch, and in recent boards, one or more Residual-current devices (RCD) or

Residual Current Breakers with Overcurrent protection RCBO,will also be incorporated.

Other names

Distribution boards are also referred to as a:

- breaker panel
- circuit breaker panel
- consumer unit, or CU
- electrical panel
- fusebox
- fuseboard
- load centre/center
- panelboard
- power breaker
- service panel
- DB board (South Africa)

North American breaker panels

The circuit breakers are generally placed in two columns. Circuit breaker panelboards are always *dead front*, that is, the operator of the circuit breakers cannot contact live electrical parts. During servicing of the distribution board itself, though, when the cover has been removed and the cables are visible, North American breaker panelboards commonly have some live parts exposed.

Breaker arrangement

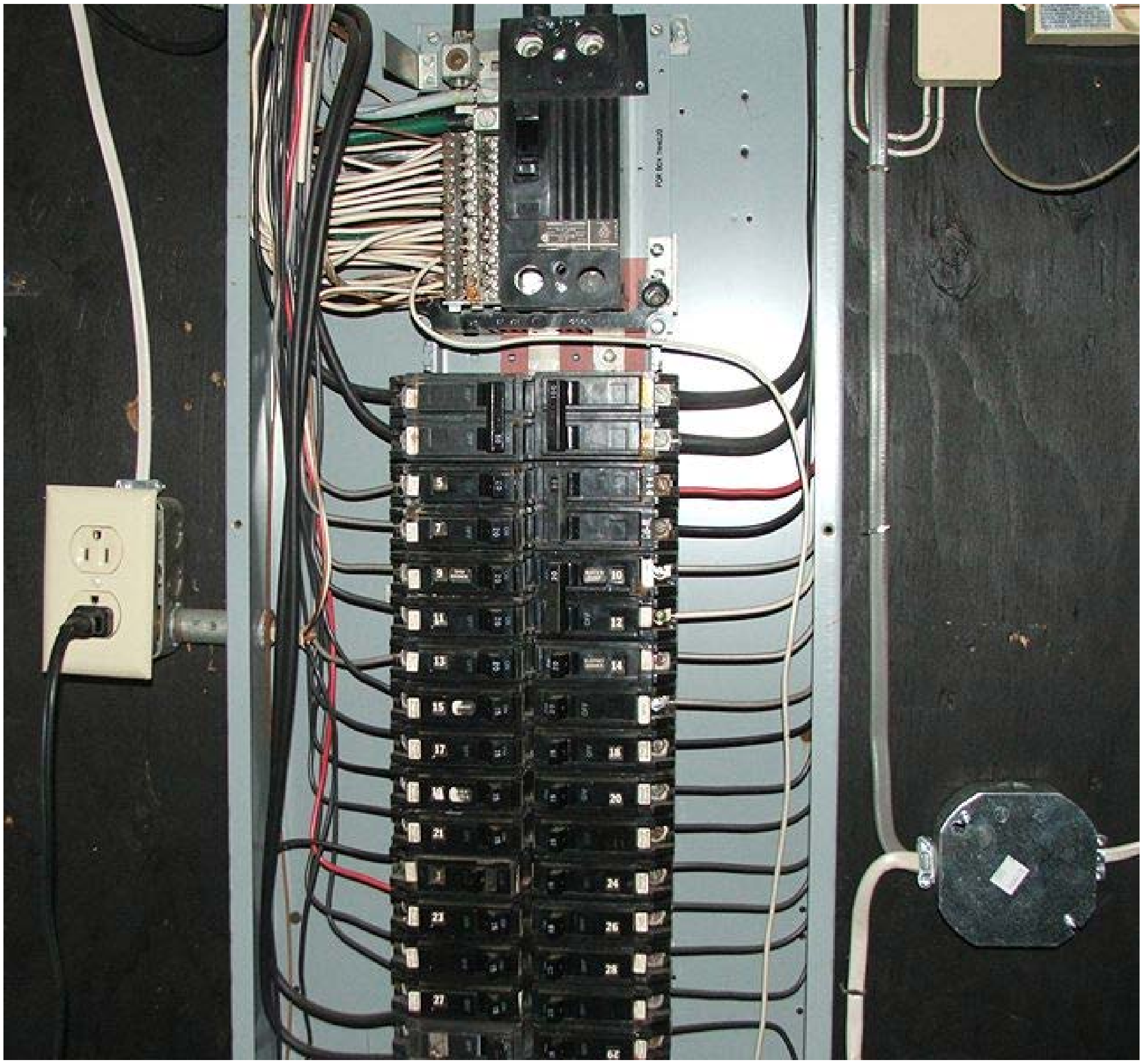
Illustration of breaker numbering in a North American type panelboard. Some labels are missing, and some lines have additional descriptive labels. The numbers on the toggles indicate the ampereage they will pass before tripping off and stopping all current. The top right breaker (Rated at 100 A) leads to a sub panel.

Breakers are usually arranged in two columns. In a US-style board, breaker positions are numbered left-to-right, along each row from top to bottom. This numbering system is universal across various competing manufacturers of breaker panels.

North American circuit breaker numbering			
Split-phase	**3-phase**	**Breakers**	
A	**A**	1	2
B	**B**	3	4
A	**C**	5	6
B	**A**	7	8
A	**B**	9	10
B	**C**	11	12

Each row is fed from a different phase (*A*, *B*, and *C* below), to allow 2- or 3-pole common-trip breakers to have one pole on each phase. In North America, it is common to wire large permanently installed equipment line-to-line. This takes two slots in the panel (two-pole) and gives a voltage of 240V if the supply system is split phase and 208 V if the supply system is three phase.

Inside a North American panel



The picture to the right shows the interior of a standard residential service, North American General Electric style breaker panel. The three power lines can be seen coming in at the top (One going to the neutral busbar to the left with all the white wires, the other two attached to the main breaker). Below it are the two rows of circuit breakers with the circuit's hot wire leading off. A line can be seen directly exiting the box and running to a NEMA 5-15 electrical receptacle with a power cord plugged into it.

UK boards

In the UK, domestic and small commercial or public installations usually have single-phase supplies at 230V (nominal standard). The main distribution boards in these installations are called consumer units (CUs), though they may be known as fuse boxes; older consumer units used fuses until the advent of mini-circuit breakers (MCBs).

A consumer unit normally has a single horizontal row of fuses or MCBs, though some older units grouped four fuses in a square arrangement. For two-rate supplies (standard/off-peak), a second CU may be added (*stacked*). Multiple CUs are also found in larger premises.

Larger commercial, public, and industrial installations generally use three-phase supplies, with distribution boards which have twin vertical rows of breakers. Larger installations will often use subsidiary distribution boards.

In both cases, modern boards handling supplies up to around 100 A (CUs) or 200 A (distribution boards) use circuit breakers and RCDs on DIN rail mountings. The main distribution board in an installation will also normally provide a main switch (known as an *incomer*) which switches the phase and neutral lines for the whole supply. (n.b., an incomer may be referred to, or sold as, an *isolator*, but this is problematic, as it will not necessarily be used as an isolator in the strict sense.)

For each phase, power is fed along a busbar. In split-phase panels, separate busbars are fed directly from the incomer, which allows RCDs to be used to protect groups of circuits. Alternatively RCBOs may be used to provide both overcurrent and residual-current protection to single circuits.

Other devices, such as transformers (e.g., for bell circuits) and contactors (relays; e.g., for large motor or heating loads) may also be used.

New British distribution boards generally have the live parts enclosed to IP20, even when the cover has been removed for servicing.

Modern CU

A typical new domestic CU used as a main panel may have from 6 to 24 ways for devices (some of which may occupy two ways), and will be split into two or more sections (e.g. a non-RCD section for alarms etc., an RCD-protected section for socket outlets, and an RCD-protected section for lighting and other built-in appliances). Secondary CUs used for outbuildings usually have 1 to 4 ways plus an RCD.

Older CUs

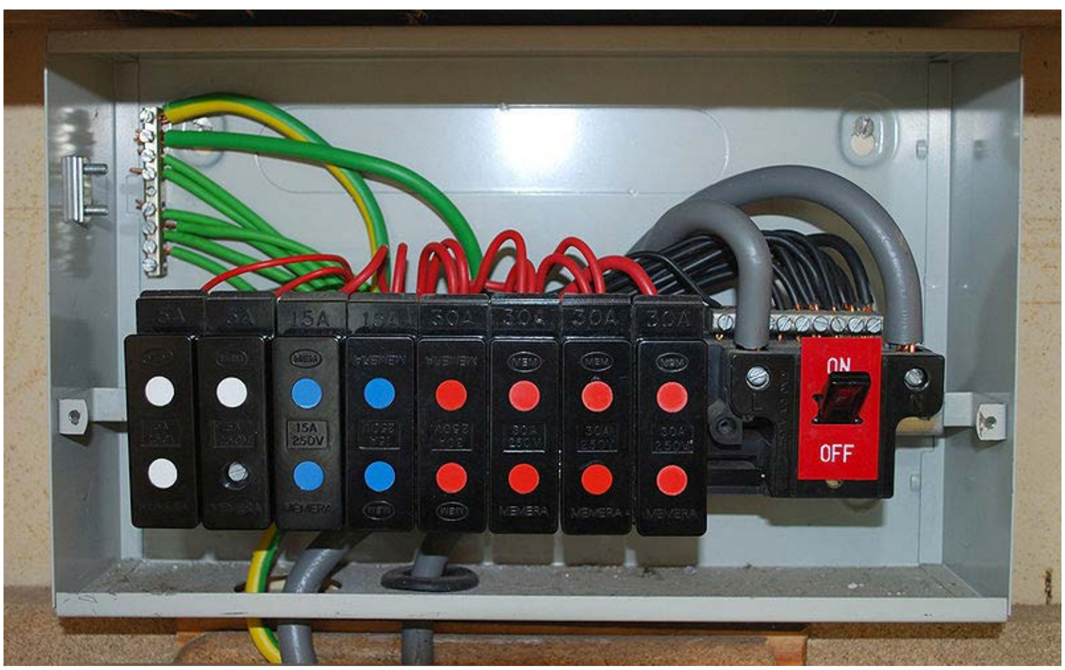
Recent (pre-17th edition wiring regulations) CUs would not usually have RCD protected sections for anything other than socket outlets, though some older CUs used RCD Incomers. Before the 1990s RCDs (and split busbars) were not standard in CUs.

Rewirable Fuse Boxes

1950s MEM rewirable fuse box (covered)

1950s MEM rewirable fuse box (open)

1970s MEM rewirable fuse box (covered)



1970s MEM rewirable fuse box (open)

Fuse Boxes usually use cartridge or rewirable fuses with no other protective device, and basic 4-ways boxes are very common. Some older boxes are made of brown-black bakelite, sometimes with a wooden base. Although their design is historic, these were standard equipment for new installs as recently as the 1980s, so they are very common. Fuseholders in these boxes may not provide protection from accidental contact with live terminals.

The popular 4-way fusebox usually has two lighting and two socket circuits, with heavy or sustained loads such as immersion heater and oven on a socket circuit. This arrangement is not recommended practice today, but it is common in existing installations. Larger boxes with more ways will have separate fuses for large loads such as immersion heater, oven and shower.

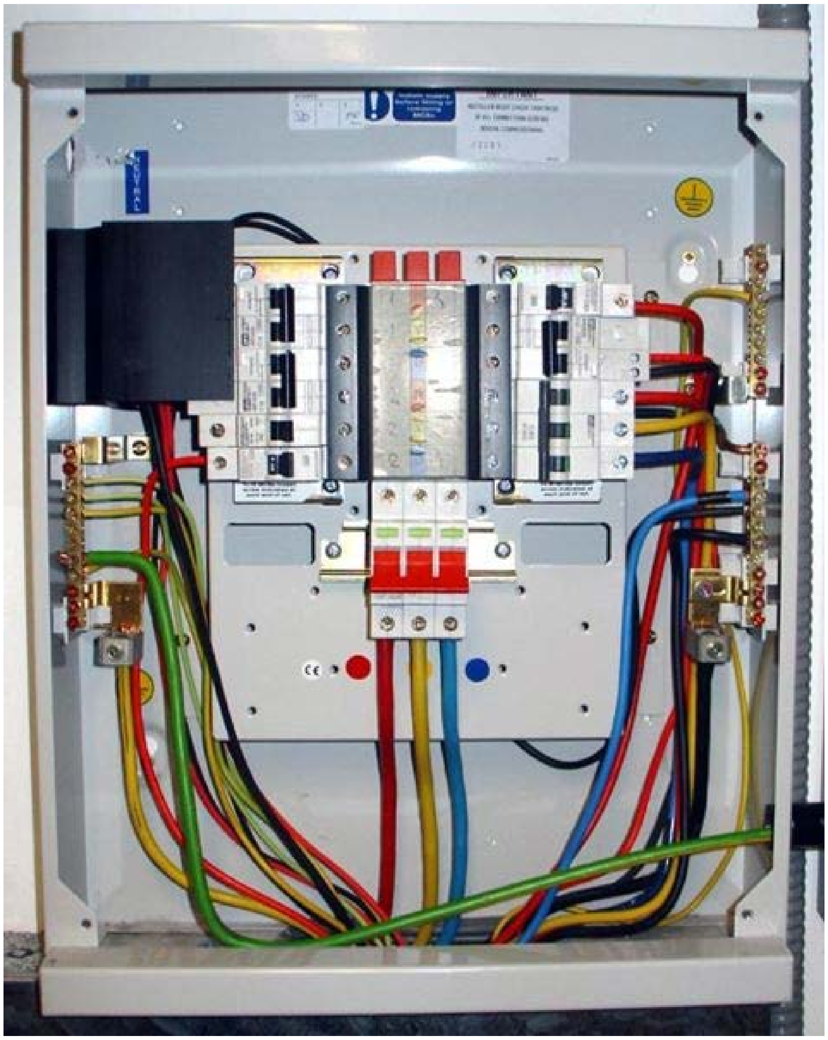
Circuit breaker retrofits

Some of these fuseboxes have had their fuse carriers replaced with plug-in miniature circuit breakers. These retrofit MCBs are typically rated at 3kA breaking capacity, but many homes or properties have prospective short circuit currents as high as 6kA. Fault currents of over 3kA are thus interrupted by the incomer fuse, should they ever occur, and the MCB would not survive.

Historic fuseboxes

A small number of pre-1950 fuseboxes are still in service. These should be treated with caution because exposed live parts are common on these boxes. The installations they supply will not meet modern standards for electrical safety. Another characteristic of very old installations is that there may be two fuses for each circuit; one on the live and one on the neutral. In rare instances, old ring circuits may be encountered with no less than 4 15 A fuses per ring, one on each of L and N, and this duplicated for each of the 2 feeds for the ring.

Inside a UK distribution board



This picture shows the interior of a typical 12-position UK distribution panel. The three incoming phase wires connect to the busbars via a main switch in the centre of the panel. On each side of the panel are two busbars, for neutral and earth. The incoming neutral connects to the lower busbar on the right side of the panel, which is in turn connected to the neutral busbar at the top left. The incoming earth wire connects to the lower busbar on the left side of the panel, which is in turn connected to the earth busbar at the top right. The cover has been removed from the lower-right neutral bar; the neutral bar on the left side has its cover in place.

Down the left side of the phase busbars are two two-pole RCBOs and two single-pole breakers, one unused. Down the right side of the busbars are a single-pole breaker, a two-pole RCBO and a three-pole breaker.

The two-pole RCBOs in the picture are not connected across two phases, but have supply-side neutral connections exiting behind the phase busbars.

The illustrated panel includes a great deal of unused space; it is likely that the manufacturer produces 18- and 24-position versions of this panel using the same chassis.

In a UK-style board, breaker positions are numbered top to bottom in the left hand column, then top to bottom in the right column. Each number is used to label one position on each phase, as below, and can be seen faintly in the photograph to the right. It remains to be seen how the new wiring colours recently introduced in the UK will affect this labelling.

Phase	Breakers	
Red	R1	R4
Yellow	Y1	Y4
Blue	B1	B4
Red	R2	R5
Yellow	Y2	Y5
Blue	B2	B5
Red	R3	R6
Yellow	Y3	Y6
Blue	B3	B6

Manufacturer differences

Most of the time, the panel and the breakers inserted into it must both be from the same company. Each company has one or more "systems", or kinds of breaker panels, that only accept breakers of that type. In Europe this is still the case, despite the adoption of a standard DIN rail for mounting and a standard cut-out shape, as the positions of the busbar connections are not standardised.

Certain panels use seemingly interchangeable 1-inch-wide (25 mm) breakers. However, a given manufacturer will often specify exactly what devices are permitted to be installed in their equipment. These assemblies have been tested and approved for use by a recognized authority. Replacing or adding equipment which "just happens to fit" can result in unexpected or even dangerous conditions. Such installations should not be done without first consulting knowledgeable sources, including manufacturers.

Location and designation

A three phase service drop enters through the rear of this main service panel consisting of three 100 ampere fuses.

For reasons of aesthetics and security, circuit breaker panels are often placed in out-of-the-way closets, attics, garages, or basements, but sometimes they are also featured as part of the aesthetic elements of a building (as an art installation, for example) or where they can be easily accessed. However, current US building codes prohibit installing a panel in a bathroom (or similar room), in closets intended for clothing, or where there is insufficient space for a worker to access it. Specific situations, such as an installation outdoors, in a hazardous environment, or in other out-of-the-ordinary locations may require specialized equipment and more stringent installation practices.

Large buildings or facilities with higher electric power demand may have multiple circuit breaker panels. In this case, the panels are often indicated by letters of the alphabet. One case is The Decon Gallery, a modern building in downtown Toronto, which has 11 breaker panels designated *A*, *B*, *C*, *D*, and so on. A backstage outlet is therefore labeled *C27*. In many such buildings, each outlet is on its own circuit breaker, and the outlets are labelled in the above specified manner to facilitate easy location of which breaker to shut off for servicing, rewiring, or the like.

In even larger buildings, such as schools, hospitals and sports/entertainment venues it is not uncommon to have scores of panels, specially designated for each building depending on how the architects and electrical engineers subdivide the building. They are commonly designated as either three-phase or single-phase and normal power or emergency power. In these set-ups they may also be designated for their use, such as distribution panels for supplying other panels, lighting panels for lights, power panels for equipment and receptacles and special uses for whatever type of building they are used in. It is also not uncommon for these panels to be located throughout the building in electric closets serving a section of the building.

In a theatre a specialty panel called a *dimmer rack* is used to feed stage lighting instruments. A US style dimmer rack has a 208Y/120 volt 3-phase feed. Instead of just circuit breakers, the rack has a solid state electronic dimmer with its own circuit breaker for each stage circuit. This is known as a *dimmer-per-circuit* arrangement. The dimmers are equally divided across the three incoming phases. In a 96 dimmer rack, there are 32 dimmers on phase A, 32 dimmers on phase B, and 32 on phase C to spread out the lighting load as equally as possible. In addition to the power feed from the supply transformer in the building, a control cable from the lighting desk carries information to the dimmers in a control protocol such as DMX-512. The information includes commands on levels, fade times, and which dimmers come up and go out during the lighting changes of the show (light cues).

Distribution boards may be surface-mounted on a wall or may be sunk into the wall. The former arrangement allows for easier alteration or addition to wiring at a later date, but the latter arrangement may look neater, particularly in a residential situation. The other problem with recessing a distribution board into a wall is that if the wall is solid a lot of brick or block may need to be removed - for this reason recessed boards are generally only fitted on new-build projects when the required space can be built into the wall.

Mobile operation

Sometimes it is desired to have a portable breaker panel, for example, for special events. In this case, a breaker panel is mounted to a board, together with various sockets. The American one pictured at the right has a cord with an L21-30 plug to supply power. Power leaves the board through four three-phase circuits: three 15 ampere circuits; and one 20 A circuit. The 15 A circuits each go to a triplex-box. The 20 A circuit goes to an L21-20 receptacle, and one leg of it goes to a 20 A duplex receptacle shown at the upper left. The neon night-lights on the upper right triplex box are to show the phase presence.

The use of a load center in this type of configuration is dangerous and violates UL and NEC rules for their use. When power distribution is required on movie sets, concert stages and theatrical venues it should be provided via products Listed "for portable power distribution."

Chapter-8

Earthing System

In electricity supply systems, an **earthing system** defines the electrical potential of the conductors relative to that of the Earth's conductive surface. The choice of earthing system has implications for the safety and electromagnetic compatibility of the power supply. Note that regulations for earthing (grounding) systems vary considerably among different countries.

A *protective earth* (PE) connection ensures that all exposed conductive surfaces are at the same electrical potential as the surface of the Earth, to avoid the risk of electrical shock if a person touches a device in which an insulation fault has occurred. It ensures that in the case of an insulation fault (a "short circuit"), a very high current flows, which will trigger an overcurrent protection device (fuse, circuit breaker) that disconnects the power supply.

A *functional earth* connection serves a purpose other than providing protection against electrical shock. In contrast to a protective earth connection, a functional earth connection may carry a current during the normal operation of a device. Functional earth connections may be required by devices such as surge suppression and electromagnetic interference filters, some types of antennas and various measurement instruments. Generally the protective earth is also used as a functional earth, though this requires care in some situations.

IEC terminology

International standard IEC 60364 distinguishes three families of earthing arrangements, using the two-letter codes **TN**, **TT**, and **IT**.

The first letter indicates the connection between earth and the power-supply equipment (generator or transformer):

T
: Direct connection of a point with earth (Latin: terra);

I
: No point is connected with earth (isolation), except perhaps via a high impedance.

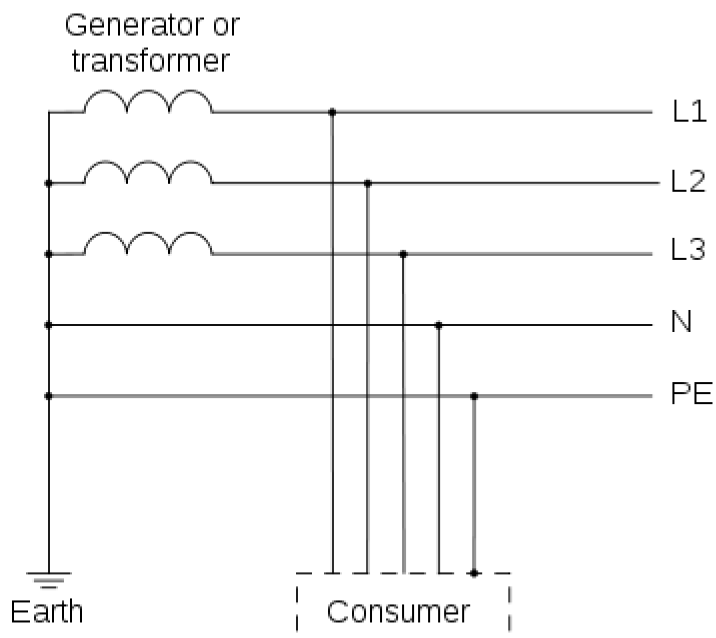
The second letter indicates the connection between earth and the electrical device being supplied:

T
: Direct connection of a point with earth

N
: Direct connection to neutral at the origin of installation, which is connected to the earth

TN networks

In a **TN** earthing system, one of the points in the generator or transformer is connected with earth, usually the star point in a three-phase system. The body of the electrical device is connected with earth via this earth connection at the transformer.



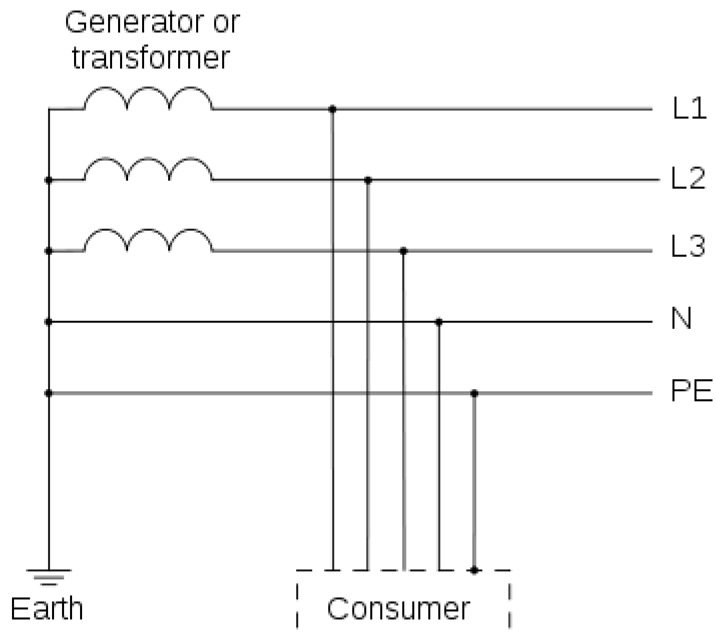
The conductor that connects the exposed metallic parts of the consumer is called *protective earth* (*PE*). The conductor that connects to the star point in a three-phase system, or that carries the return current in a single-phase system, is called *neutral* (*N*). Three variants of TN systems are distinguished:

TN−S
: PE and N are separate conductors that are connected together only near the power source.

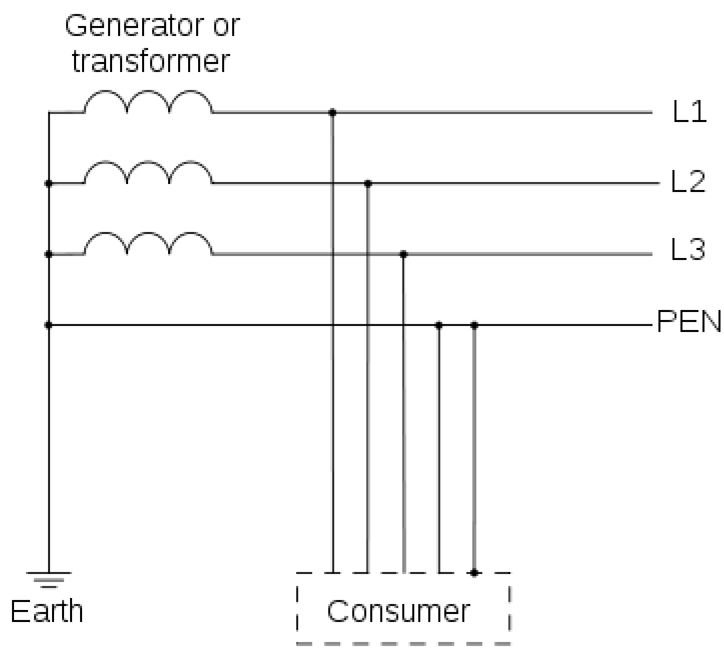
TN−C
: A combined PEN conductor fulfills the functions of both a PE and an N conductor. Rarely used.

TN−C−S

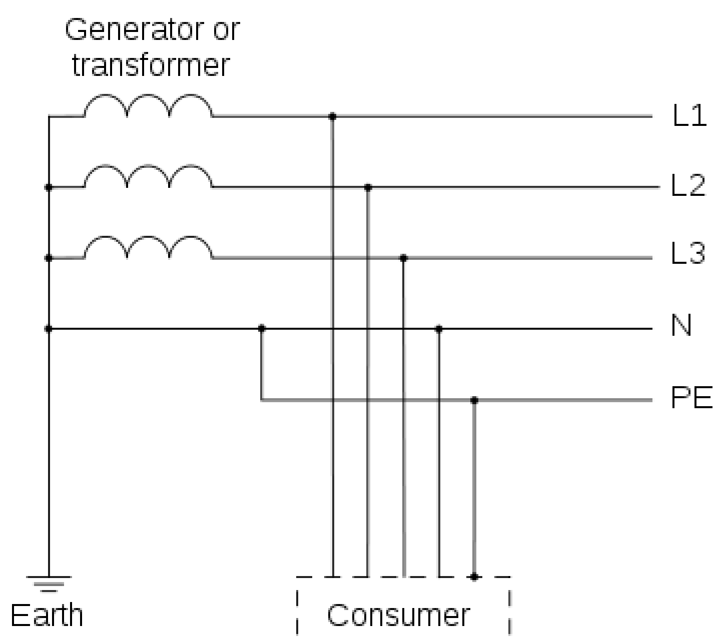
Part of the system uses a combined PEN conductor, which is at some point split up into separate PE and N lines. The combined PEN conductor typically occurs between the substation and the entry point into the building, and separated in the service head. In the UK, this system is also known as *protective multiple earthing (PME)*, because of the practice of connecting the combined neutral-and-earth conductor to real earth at many locations, to reduce the risk of broken neutrals - with a similar system in Australia being designated as *multiple earthed neutral (MEN)*.



TN-S: separate protective earth (PE) and neutral (N) conductors from transformer to consuming device, which are not connected together at any point after the building distribution point.



TN-C: combined PE and N conductor all the way from the transformer to the consuming device.



TN-C-S earthing system: combined PEN conductor from transformer to building distribution point, but separate PE and N conductors in fixed indoor wiring and flexible power cords.

It is possible to have both TN-S and TN-C-S supplies from the same transformer. For example, the sheaths on some underground cables corrode and stop providing good earth connections, and so homes where "bad earths" are found get converted to TN-C-S.

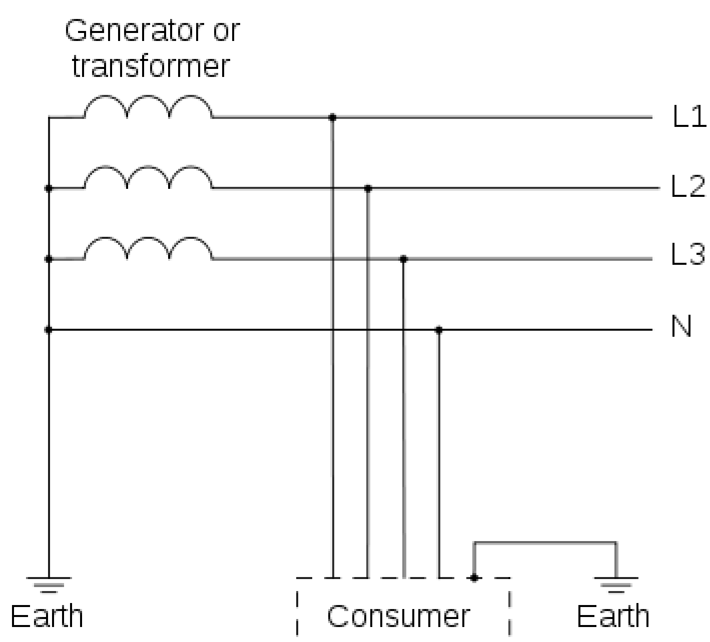
TT network

In a **TT** earthing system, the protective earth connection of the consumer is provided by a local connection to earth, independent of any earth connection at the generator.

The big advantage of the TT earthing system is the fact that it is clear of high and low frequency noises that come through the neutral wire from various electrical equipment connected to it. This is why TT has always been preferable for special applications like telecommunication sites that benefit from the interference-free earthing. Also, TT does not have the risk of a broken neutral.

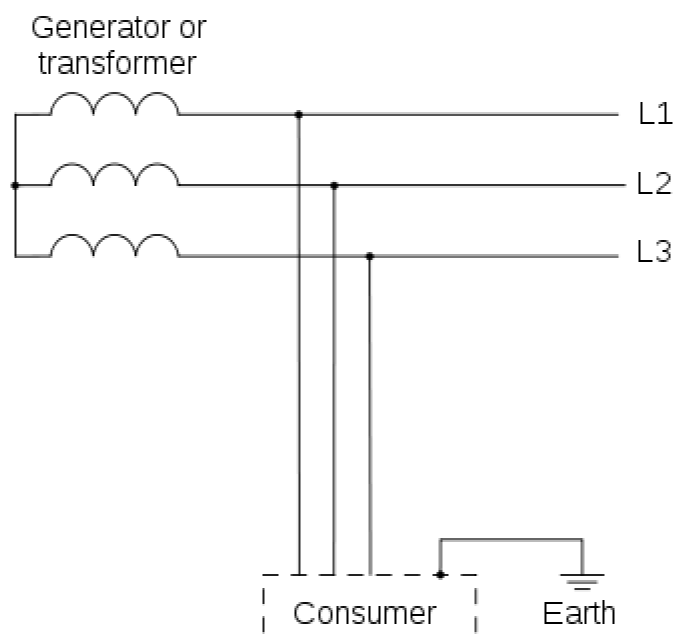
In locations where power is distributed overhead and TT is used, installation earth conductors are not at risk should any overhead distribution conductor be fractured by, say, a fallen tree or branch.

In pre-RCD era, the TT earthing system was unattractive for general use because of its worse capability of accepting high currents in case of a live-to-PE short circuit (in comparison with TN systems). But as residual current devices mitigate this disadvantage, the TT earthing system becomes attractive for premises where all AC power circuits are RCD-protected.



IT network

In an **IT** network, the distribution system has no connection to earth at all, or it has only a high impedance connection. In such systems, an insulation monitoring device is used to monitor the impedance. For safety reasons this network is not accepted under European norms.



Other terminologies

While the national wiring regulations for buildings of many countries follow the IEC 60364 terminology, in North America (United States and Canada), the term "equipment grounding conductor" refers to equipment grounds and ground wires on branch circuits, and "grounding electrode conductor" is used for conductors bonding an earth ground rod (or similar) to a service panel. "Grounded conductor" is the system "neutral".

Properties

Cost

- TN networks save the cost of a low-impedance earth connection at the site of each consumer. Such a connection (a buried metal structure) is required to provide *protective earth* in IT and TT systems.
- TN-C networks save the cost of an additional conductor needed for separate N and PE connections. However, to mitigate the risk of broken neutrals, special cable types and lots of connections to earth are needed.
- TT networks require proper RCD protection.

Fault path impedance

If the fault path between accidentally energized objects and the supply connection has low impedance, the fault current will be so large that the circuit overcurrent protection device (fuse or circuit breaker) will open to clear the ground fault. Where the earthing system does not provide a low-impedance metallic conductor between equipment enclosures and supply return (such as in a TT separately earthed system), fault currents are smaller, and will not necessarily operate the overcurrent protection device. In such case a residual current detector is installed to detect the current leaking to ground and interrupt the circuit.

Safety

- In TN, an insulation fault is very likely to lead to a high short-circuit current that will trigger an overcurrent circuit-breaker or fuse and disconnect the L conductors. With TT systems, the earth fault loop impedance can be too high to do this, or too high to do it quickly, so an RCD (or formerly ELCB) is usually employed. The provision of a Residual-current device (RCD) or ELCB to ensure safe disconnection makes these installations EEBAD (Earthed Equipotential Bonding and Automatic Disconnection).
- Many 1950s and earlier earlier TT installations in the UK may lack this important safety feature. Non-EEBAD installations are capable of the whole installation CPC (Circuit Protective Conductor) remaining live for extended periods under fault conditions, which is a real danger.
- In TN-S and TT systems (and in TN-C-S beyond the point of the split), a residual-current device can be used as an additional protection. In the absence of any insulation fault in the consumer device, the equation $I_{L1}+I_{L2}+I_{L3}+I_{N} = 0$ holds, and an RCD can disconnect the supply as soon as this sum reaches a threshold (typically 10-500 mA). An insulation fault between either L or N and PE will trigger an RCD with high probability.
- In IT and TN-C networks, residual current devices are far less likely to detect an insulation fault. In a TN-C system, they would also be very vulnerable to unwanted triggering from contact between earth conductors of circuits on different RCDs or with real ground, thus making their use impracticable. Also, RCDs usually isolate the neutral core. Since it is unsafe to do this in a TN-C system, RCDs on TN-C should be wired to only interrupt the live conductor.
- In single-ended single-phase systems where the Earth and neutral are combined (TN-C, and the part of TN-C-S systems which uses a combined neutral and earth core), if there is a contact problem in the PEN conductor, then all parts of the earthing system beyond the break will rise to the potential of the L conductor. In an unbalanced multi-phase system, the potential of the earthing system will move towards that of the most loaded live conductor. Therefore, TN-C connections must not go across plug/socket connections or flexible cables, where there is a higher probability of contact problems than with fixed wiring. There is also a risk if a cable is damaged, which can be mitigated by the use of concentric cable construction and/or multiple earth electrodes. Due to the (small) risks of the lost

neutral, use of TN-C-S supplies is banned for caravans and boats in the UK, and it is often recommended to make outdoor wiring TT with a separate earth electrode.

- In IT systems, a single insulation fault is unlikely to cause dangerous currents to flow through a human body in contact with earth, because no low-impedance circuit exists for such a current to flow. However, a first insulation fault can effectively turn an IT system into a TN system, and then a second insulation fault can lead to dangerous body currents. Worse, in a multi-phase system, if one of the live conductors made contact with earth, it would cause the other phase cores to rise to the phase-phase voltage relative to earth rather than the phase-neutral voltage. IT systems also experience larger transient overvoltages than other systems.
- In TN-C and TN-C-S systems, any connection between the combined neutral-and-earth core and the body of the earth could end up carrying significant current under normal conditions, and could carry even more under a broken neutral situation. Therefore, main equipotential bonding conductors must be sized with this in mind; use of TN-C-S is inadvisable in situations such as petrol stations, where there is a combination of lots of buried metalwork and explosive gases.

Electromagnetic compatibility

- In TN-S and TT systems, the consumer has a low-noise connection to earth, which does not suffer from the voltage that appears on the N conductor as a result of the return currents and the impedance of that conductor. This is of particular importance with some types of telecommunication and measurement equipment.
- In TT systems, each consumer has its own connection to earth, and will not notice any currents that may be caused by other consumers on a shared PE line.

Regulations

- In the United States National Electrical Code and Canadian Electrical Code the feed from the distribution transformer uses a combined neutral and grounding conductor, but within the structure separate neutral and protective earth conductors are used (TN-C-S). The neutral must be connected to the earth (ground) conductor only on the supply side of the customer's disconnecting switch. Additional connections of neutral to ground within the customer's wiring are prohibited.
- In Argentina, France (TT) and Australia (TN-C-S), the customers must provide their own ground connections.
- Japan is governed by PSE law, and uses TT earthing in most installations.
- In Australia, the Multiple Earthed Neutral (MEN) earthing system is used and is described in Section 5 of AS 3000. For an LV customer, it is a TN-C system from the transformer in the street to the premises, (the neutral is earhed multiple times along this segment), and a TN-S system inside the installation, from the Main Switchboard downwards. Looked at as a whole, it is a TN-C-S system.

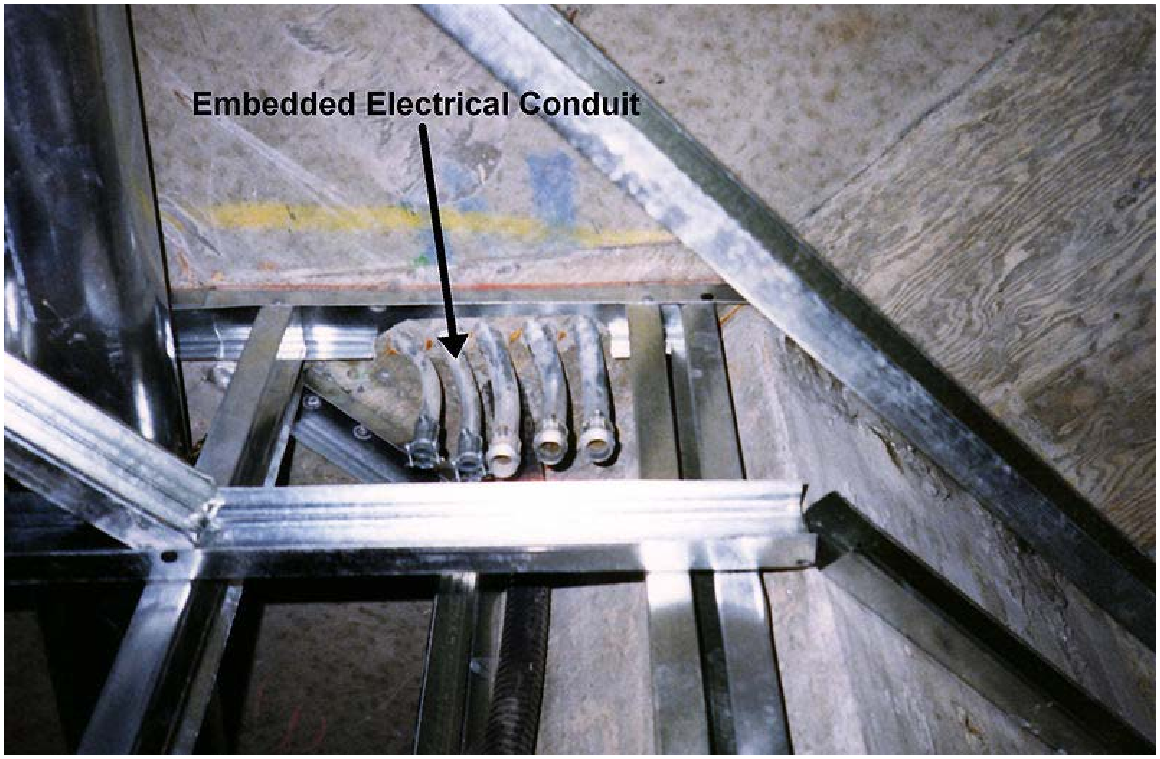
Application examples

- Most modern homes in Europe have a TN-C-S earthing system. The combined neutral and earth occurs between the nearest transformer substation and the service cut out (the fuse before the meter). After this, separate earth and neutral cores are used in all the internal wiring.
- Older urban and suburban homes in the UK tend to have TN-S supplies, with the earth connection delivered through the lead sheath of the underground lead-and-paper cable.
- Some older homes, especially those built before the invention of residual-current circuit breakers and wired home area networks, use an in-house TN-C arrangement. This is no longer recommended practice.
- Laboratory rooms, medical facilities, construction sites, repair workshops, mobile electrical installations, and other environments that are supplied via engine-generators where there is an increased risk of insulation faults, often use an IT earthing arrangement supplied from isolation transformers. To mitigate the two-fault issues with IT systems, the isolation transformers should supply only a small number of loads each and/or should be protected with an insulation monitoring device (generally used only by medical, railway or military IT systems, because of cost).
- In remote areas, where the cost of an additional PE conductor outweighs the cost of a local earth connection, TT networks are commonly used in some countries, especially in older properties or in rural areas, where safety might otherwise be threatened by the fracture of an overhead PE conductor by, say, a fallen tree branch. TT supplies to individual properties are also seen in mostly TN-C-S systems where an individual property is considered unsuitable for TN-C-S supply.
- In Australia, and Israel the TN-C-S system is in use; however, the wiring rules currently state that, in addition, each customer must provide a separate connection to earth via both a water pipe bond (if metallic water pipes enter the consumer's premises) and a dedicated earth electrode. In Australia, new installations must also bond the foundation concrete re-enforcing under wet areas to the earth conductor (AS3000), typically increasing the size of the earthing, and provides an equipotential plane in areas such as bathrooms. In older installations, it is not uncommon to find only the water pipe bond, and it is allowed to remain as such, but the additional earth electrode must be installed if any upgrade work is done. The protective earth and neutral conductors are combined until the consumer's neutral link (located on the customer's side of the electricity meter's neutral connection) - beyond this point, the protective earth and neutral conductors are separate.

Chapter-9

Electrical Conduit

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



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

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

An **electrical conduit** is an electrical piping system used for protection and routing of electrical wiring. Electrical conduit may be made of metal, plastic, fiber, or fired clay. Flexible conduit is available for special purposes.

Conduit is generally installed by electricians at the site of installation of electrical equipment. Its use, form, and installation details are often specified by wiring regulations, such as the U.S. NEC or other national or local code. The term "conduit" is commonly used by electricians to describe any system that contains electrical conductors, but the term has a more restrictive definition when used in wiring regulations.

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

Comparison with other wiring methods

Electrical conduit provides very good protection to enclosed conductors from impact, moisture, and chemical vapors. Varying numbers, sizes, and types of conductors can be pulled into a conduit, which simplifies design and construction compared to multiple runs of cables or the expense of customised composite cable. Wiring systems in buildings are subject to frequent alterations. Frequent wiring changes are made simpler and safer through the use of electrical conduit, as existing conductors can be withdrawn and new conductors installed, with little disruption along the path of the conduit. A conduit system can be made waterproof or submersible. Metal conduit can be used to shield sensitive circuits from electromagnetic interference, and also can prevent emission of such interference from enclosed power cables.

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

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

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

The cost of conduit installation is higher than other wiring methods due to the cost of materials and labor. In applications such as residential construction, the high degree of physical damage protection is not required so the expense of conduit is not warranted. Conductors installed within conduit cannot dissipate heat as readily as those installed in open wiring, so the current capacity of each conductor must be reduced if many are installed in one conduit. It is impractical, and prohibited by wiring regulations, to have more than 360 degrees of total bends in a run of conduit, so special outlet fittings must be provided to allow conductors to be installed without damage in such runs. While metal conduit can be used as a grounding conductor, the circuit length is limited. A long run of conduit as grounding conductor will not allow proper operation of overcurrent devices on a fault, for example.

Types of conduit

Conduit systems are classified by the wall thickness, mechanical stiffness, and material used to make the tubing.

Rigid Metal Conduit (RMC)

Rigid Metal Conduit (RMC) is a thick threaded tubing, usually made of coated steel, stainless steel or aluminum.

Rigid Nonmetallic Conduit (RNC)

Rigid Nonmetallic Conduit (RNC) is a non-metallic unthreaded tubing.

Galvanized rigid conduit (GRC)

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

Electrical metallic tubing (EMT)

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

Electrical Nonmetallic Tubing (ENT)

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

Flexible Metallic Conduit (FMC)

Flexible metallic conduit used in an underground parking facility.

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

Cutting FMC requires a specialized hand tool with a rotary abrasive disc to creates a small incision into the ribbing so that a twisting motion separates the segments. The disc cuts deep enough to sever the armor coil but not so deep that it could damage the inside conductors.

Short segments of FMC called *whips* are often used as circuit "pigtails" between fixtures and a junction box, especially in suspended ceilings. Whip assemblies save a great deal of repetitive labor when installations require several pigtails for several fixtures.

Flexible metal conduit coated with a UV-resistant polymer is liquid-tight when installed with appropriate glandular fittings containing liquid-tight features such as O-rings.

Wiring regulations vary; in locales following the U.S. National Electric Code (NEC), flexible metallic conduit may serve as an equipment-grounding conductor. Other areas may require a bonding wire for equipment grounding. The bonding wire in direct contact with the interior of the conduit creates a lower resistance grounding conductor than the conduit alone.

Liquidtight Flexible Metal Conduit (LFMC)

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

Flexible Metallic Tubing (FMT)

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

Liquidtight Flexible Nonmetallic Conduit (LFNC)

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

Aluminum conduit

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

Intermediate metal conduit (IMC)

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

PVC conduit

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

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

Plastic tubing for use as electrical conduit.

Other metal conduits

In extreme corrosion environments where plastic coating of the tubing is insufficient, conduits may be made from stainless steel, bronze or brass.

Underground conduit

Large diameter (more than 2 inch/50 mm) conduit may be installed underground between buildings to allow installation of power and communication cables. An assembly of these conduits, often called a duct bank, may either be directly buried in earth or encased in concrete. A duct bank will allow replacement of damaged cables between buildings or additional power and communications circuits to be added, without the expense of excavation of a trench. While metal conduit is occasionally used for burial, usually PVC, polyethylene or polystyrene plastics are now used due to lower cost. Formerly, compressed asbestos fiber mixed with cement was used for some underground installations. Telephone and communications circuits were installed in fired-clay conduit.

Comparison of some types of conduit

Relative to rigid galvanized steel conduit, 3/4 inch (21 metric) size

Relative	RGS	Aluminum	IMC	EMT	PVC
Labor	1.0	0.89	0.89	0.62	0.55
Weight	1.0	0.34	0.76	0.42	0.20
Material cost	1.0	0.99	0.84	0.35	0.43

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

Fittings

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

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

Couplings connect two pieces of conduit together.

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

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

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

Conduit bodies

A *conduit body* is used to provide access to wires placed within conduit. This differs from a junction box, which both allows access for pulling wires and space for splices. Conduit bodies are commonly referred to as "***condulets***", a term trademarked by Cooper Crouse-Hinds company, a division of Cooper Industries.

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

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

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

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

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

Other wireways

Surface Mounted Raceway (wire molding)

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

Advantages

- It allows one to add new wiring to an existing building without removing or cutting holes into the drywall or lath and plaster.
- It allows circuits to be easily locatable and accessible for future changes thus enabling minimum effort upgrades.

Disadvantages

- Its appearance may not be acceptable to all observers.

Trunking

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

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

In North American practice "wire trough" or "lay-in wireways" are terms used to designate similar products, but these are never used enclosed in masonry or a wall.

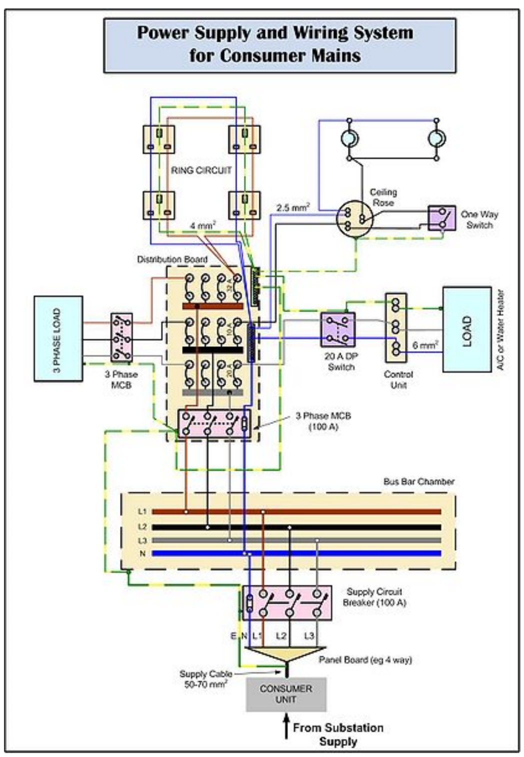
Passive fire protection

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

Chapter-10

Consumer Mains Wiring

Domestic **consumer mains wiring** refers to the wiring in the house hold premises and low voltage installations. Even though arbitrary electric wiring demands detailed calculations for selection of conductor sizes, circuit breakers, voltage drops and so on, for domestic wiring some standard methods and component sizes are used, as supported by IEE wiring regulations.



An illustrative consumer mains wiring

Distribution Board

A distribution board (or panelboard) is a component of an electricity supply system which divides an electrical power feed into subsidiary circuits, while providing a protective fuse or circuit breaker for each circuit, in a common enclosure. Normally, a main switch, and in recent boards, one or more Residual-current devices (RCD) or Residual Current Breakers with Overcurrent protection (RCBO), will also be incorporated. The RCDs are used for earth leakage protection, while RCBOs combines RCDs with overcurrent protection. In a UK-style board, breaker positions are numbered top to bottom in the left hand column, then top to bottom in the right column. Modern consumer units supply up to around 100 A from the input.

Supply voltage

Since the early 1970's, the supply voltage in UK domestic premises has been 240 V AC (RMS) at 50 Hz. In 1988, a Europe-wide agreement was reached to change the various national voltages, which ranged at the time from 220 V to 240 V, to a common European standard of 230 V (CENELEC Harmonization Document HD 472 S1:1988). As a result, the standard nominal supply voltage in domestic single-phase 50 Hz installations in the UK has been 230 V AC (RMS) since 1 January 1995 (Electricity Supply Regulations, SI 1994, No. 3021).

Cable types used

The following are the cable types typically used in domestic wiring

Internal wiring

- Single core PVC insulated cables (fixed internal wiring)
- Flexible cords

Supply side wiring

- 2/3/4 core PVC insulated, SWA, PVC sheathed cables
- PVC Insulated, PVC sheathed (Unarmoured Cables)
- Three and four cores XLPE insulated, SWA, PVC sheathed cables

Colour code of conductors

The colour code for wire insulation accepted by the European Union (IEC 60446), including UK from 31 March 2004, is shown in the table below. The old colour code followed by British standard, which is still continued in many older installations is shown.

Conductor	Old Colour code	New Colour Code
L (single phase)	Red (or yellow/white/blue)	Brown
L1	Red	Brown
L2	Yellow (or white)	Black
L3	Blue	Grey
N	Black	Blue
Protective Conductor	Green & Yellow (or Green)	Green & Yellow

Selection of conductors and circuit breakers

The selection of conductors must be done taking into consideration both maximum voltage drop allowed at the load end and also the current carrying capacity of the conductor. Conductor size and voltage drop tables are available to do the selection, which is based on the load current supplied.

The choice of circuit breaker is also done based on the normal rated current of the circuit. Modern circuit breakers have overload and short circuit current protection combined. The overload protection is for protection of the equipment against sustained small to medium increase in current above the rated current while short circuit protection is for the protection of the conductors against high over currents due to short circuits.

For domestic circuits the following choices are typically adopted for selecting conductor and circuit breaker sizes.

CB and conductor Selection

Capacity (A)	Main conductor size mm^2 (copper)	Earth conductor size mm^2	Circuit breaker capacity
Up to 600 W	1.5	1.5	5 A
600-1200 W	1.5/2.5	1.5	10 A
1200-1800 W	2.5/4	2.5	15 A
Ring circuit (floor area 100 m2)	4.0	4.0	30/32 A
A2 Radial Circuit (floor area 50 m2)	4.0	4.0	30/32 A
A3 Radial Circuit (floor area 20 m2)	2.5	2.5	20 A
Air conditioner (1.5 ton)	6.0	6.0	30/32 A
Cooker	6.0	6.0	30/32 A
Water Heater	4.0	4.0	20 A

For distribution boards the incomer circuit breaker rating depends on the actual current demand at that board. For this the maximum demand and diversity is taken into consideration based on which the probable current is calculated. Diversity refers to the condition that all appliances are not likely to be working all at the same time or at their maximum ratings. From this the maximum demand is calculated and the currents are added to determine the load current and hence the rating of the circuit breaker.

IEE recommends these current demands and diversity factors for various loads to determine the load current and rating of overcurrent protective device.

Outlet point or equipment	**Assumed load**	**Diversity factor**
socket outlet 2 A	0.5 A	25%
other socket outlets	rated current	50%
Light outlet (per lamp holder)	100 W	50%
Domestic cooker	10 A + 30% remainder + 5A for auxiliary socket	
Other stationary equipment	BS current rating or normal current	

Isolating Devices

Single pole switches are most commonly used. These switches isolate only the line conductor feeding the load and are used for lighting and other smaller loads. For larger loads like Air conditioner, cooker, water heater and other fixed appliances a double pole switch is used, which isolates also the neutral, for more safety. A three pole isolator or circuit breaker is used for three phase loads, and also at the distribution board which isolates all the phases as well as the neutral.

Ring Circuit

Ring circuit is feeding the socket outlets within a ring which starts and ends at the distribution board at the points. This applies for both live, neutral and earth conductors. This design enables the use of smaller-diameter wire than would be used in a radial circuit of equivalent total current. Ideally, the ring acts like two radial circuits proceeding in opposite directions around the ring, the dividing point between them dependent on the distribution of load in the ring. If the load is evenly split across the two directions, the current in each direction is half of the total, allowing the use of wire with half the current-carrying capacity. In practice, the load does not always split evenly, so thicker wire is used.

Radial circuit

A radial circuit is one where power is transmitted from point to point by a single length of cable linking each point to the next. It starts at the main switch or fuse and simply terminates at the last connected device. It may branch at a connection point. Lighting circuits are normally wired in this way, but it may also be used for low power socket circuits.

Division of loads between phases

The loads are usually divided approximately equally between the three phases. While three phase loads take balanced power from the three phases, the single phase loads are distributed to ensure equal loading of the three phases. Each row of breakers in the distribution board is fed from a different phase (A, B and C), to allow 3-pole common-trip breakers to have one pole on each phase.

Earthing

Earthing refers to connecting the exposed conductive part of electrical equipment and also the extraneous conductive parts of earthed bodies like water pipe to the general mass of the earth to carry away safely any fault current that may arise due to ground faults. This is done to minimize the danger of electric shock due to human contact with live parts which could result from bad insulation and insulation failures.In domestic wiring earthing of equipment is done by bonding together the earth points and metallic parts of the appliances and earthed bodies using Green/Yellow wire coming from the consumer main earthing terminal. The earth terminal is in turn connected to either consumer's earth electrode (TT system) or to the earth point given by the supplier (TN system).

Chapter-11

Multiway Switching

In building wiring, **multiway switching** is interconnection of two or more light switches to control lighting from more than one location. This allows lighting in a hallway or stairwell to be controlled from either end.

Three-way and four-way

Three-way and four-way switches make it possible to control a light from multiple locations, such as the top and bottom of a stairway, or either end of a long hallway. These switches are externally similar to single-pole switches, but have extra connections which allow two circuits to be controlled. Toggling the switch disconnects one circuit and connects the other.

Electrically, a three-way switch is a single-pole, double-throw (SPDT) switch. By connecting two of these switches together, toggling either switch changes the state of the light from off to on, or on to off. A four-way switch has two pairs of terminals which it connects either straight through, or crossed over. By connecting one or more four-way switches in-line with three-way switches at either end, the light can be controlled from three or more locations. Toggling any switch changes the state of the light from off to on, or on to off.

Two locations

Switching a load on or off from two locations (for instance, turning a light on or off from either end of a flight of stairs) requires two SPDT switches. There are two basic methods or systems of wiring to achieve this.

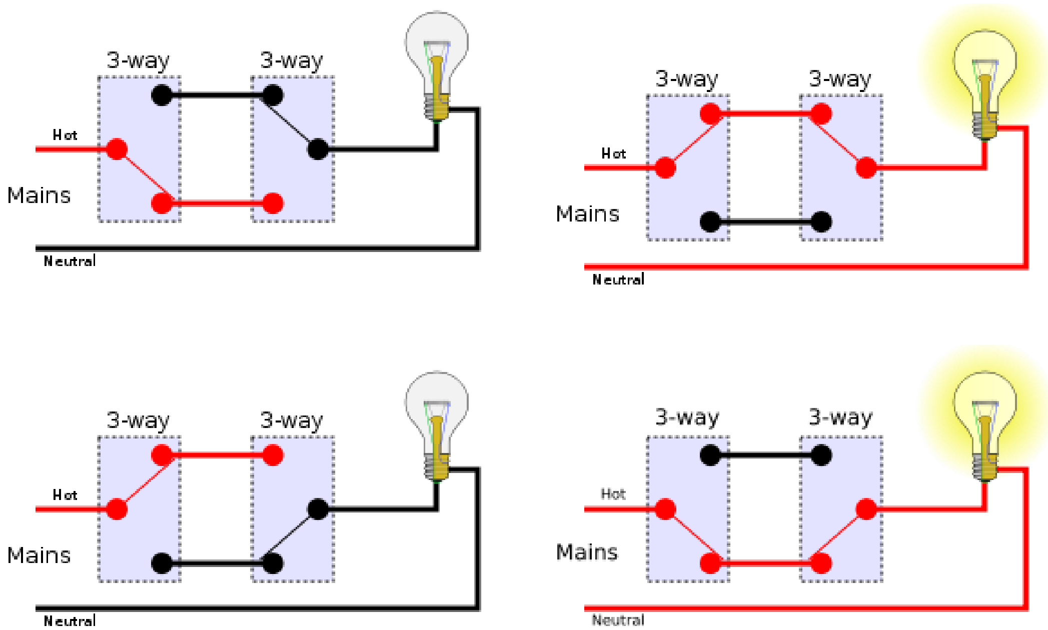
Traveler system

The Traveler system may also be called the "Common system", due to the line and load of the system being connected to the common terminal of their respective three-way switch.

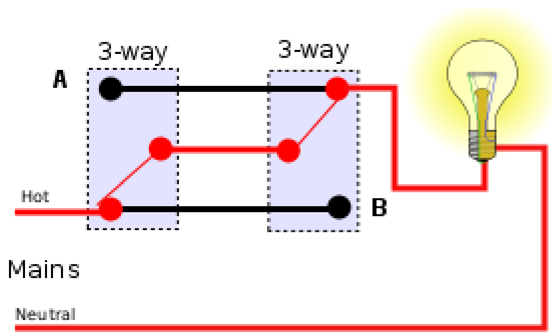
In the Traveler system, the line hot is fed into the common terminal of one of the switches; the switches are then connected by a wire pair called "Travelers", as shown, and the lamp is connected to common of a second switch. This method requires two wires between the switches.

Using the Traveler system, there are four possible combinations of switch positions: two with the light on and two with the light off.

Off **On**



Alternative system



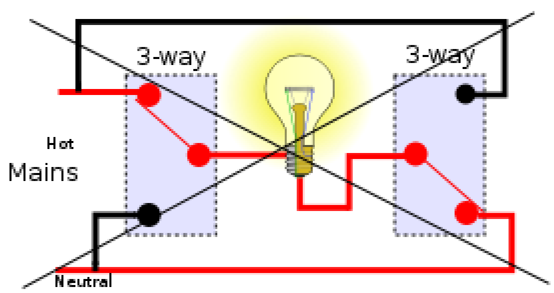
The "California 3-way" or "Coast 3-way" connection never connects the lamp socket shell to the live terminal. An additional lamp can be connected at A as a pilot lamp or for a long corridor. A receptacle can be connected at B since that terminal is always live. For example, in an outbuilding, this would save one wire.

The alternative system is also known as the **California 3-way** or the **coast 3-way**. It is a method of wiring using four conductors and two three-way switches. It allows for a hot receptacle at both ends of the circuit as well as switched light outlets on both ends. Its main benefit is that it saves on conductors when the wire to the light is located near the wire from the mains, since they are both in the same switch box. It can also light a lamp (or a second lamp) that is near the second switch box without having to pass an extra wire (with the standard system an extra wire would be needed). Its main drawback is that it is wired up to the 3-way switches in a non-standard manner that can cause confusion and mis-wiring for anyone who follows the initial installer. When wired correctly, it does not pose an electrical code violation as the neutral is never switched. While this method requires three wires between the switches, it also gives the advantage of allowing loads at both ends of the switched circuit to be controlled from either end.

The alternative system is to join the three terminals of one switch to the corresponding terminals on the other switch. The incoming supply and the lamp are connected as shown. This method requires three wires between the switches.

The alternative system should not be confused with the Carter system. The alternative system is legal, but can be confusing.

Carter system



The Carter system is not recommended.

The **Carter system** was a method of wiring 3-way switches in the era of knob and tube wiring. Two of the four switch combinations are dangerous, and this wiring method has been prohibited by the National Electrical Code since 1923.

In the Carter system, the incoming live (energized) and neutral wires are connected to the traveler screws of both 3-way switches, and the lamp is connected between the common screws of the two switches. If both switches are flipped to hot or both are flipped to neutral, there is no light; but if they are switched to opposite positions, there is light. The advantage of this method is that it uses just one wire to the light from each switch, having a hot and neutral in both switches.

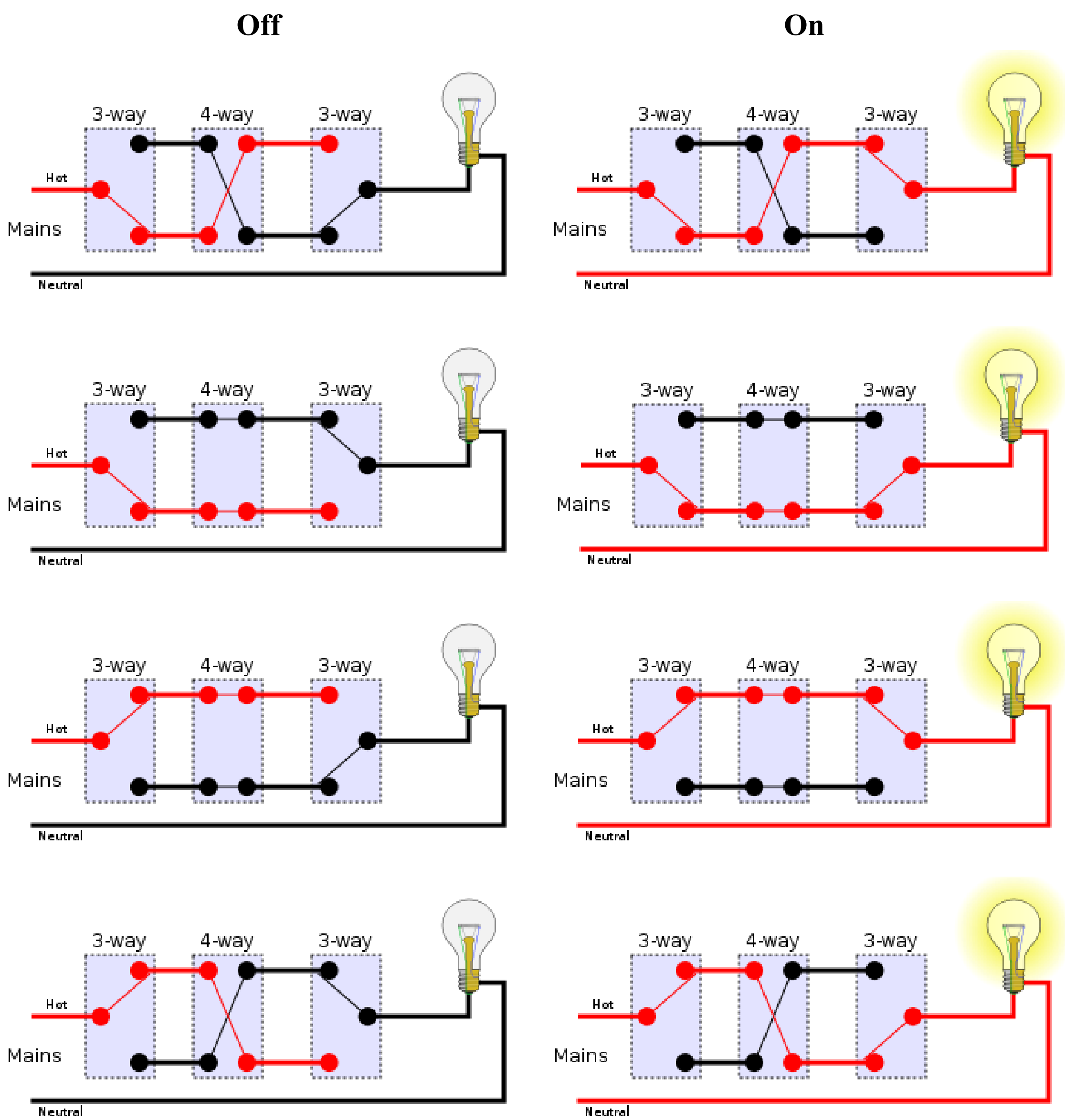
The major problem with this method is that two switch combinations apply the live (hot) wire to the outer shell of the light socket, presenting a dangerous electrical shock hazard. The lampholder shell may still be energized even with the light off, which poses a risk when changing a bulb. This method is prohibited in building wiring where the neutral and live conductors must be distinguished.

More than two locations

For more than two locations, two of the interconnecting wires must be passed through an intermediate switch, wired to swap them over. Any number of intermediate switches can be inserted, allowing for any number of locations. This requires two wires along the sequence of switches.

Traveler system

Using the Traveler system, there are eight possible combinations of switch positions: four with the light on and four with the light off. N.B. This diagram also uses the American electrical wiring names.



As mentioned above, the above circuit can be extended by using multiple 4-way switches between the 3-way switches to extend switching ability to any number of locations.

Chapter-12

Ring Circuit

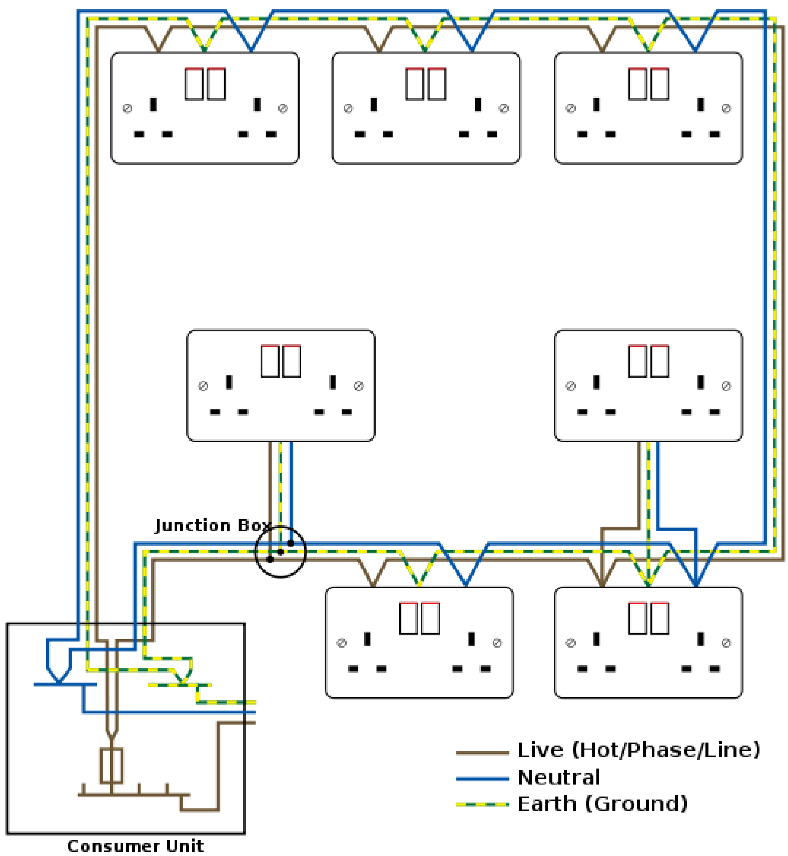


Diagram of a possible configuration of ring final circuit. Consumer unit (fuse box) is at bottom left.

In electricity supply, a **ring final circuit** or **ring circuit** (informally also **ring main** or just **ring**) is an electrical wiring technique developed and primarily used in the United Kingdom that provides *two* independent conductors for live, neutral and protective earth (ground) within a building for each connected load or socket.

This design enables the use of smaller-diameter wire than would be used in a radial circuit of equivalent total current. Ideally, the ring acts like two radial circuits proceeding in opposite directions around the ring, the dividing point between them dependent on the distribution of load in the ring. If the load is evenly split across the two directions, the current in each direction is half of the total, allowing the use of wire with half the current-carrying capacity. In practice, the load does not always split evenly, so thicker wire is used.

Description

In a single-phase system, the ring starts at the consumer unit (also known as *fuse box* or *breaker box*), visits each socket in turn, and then returns to the consumer unit. In a three-phase system, the ring (which is almost always single-phase) is fed from a single-pole breaker in the distribution board.

Ring circuits are commonly used in British wiring with fused 13 A plugs to BS 1363. They are generally wired with 2.5 mm^2 cable and protected by a 30 A fuse, an older 30 A circuit breaker, or a European harmonised 32 A circuit breaker. Sometimes 4 mm^2 cable is used if very long cable runs (to help reduce volt-drop) or derating factors such as thermal insulation are involved. 1.5 mm^2 mineral-insulated copper-clad cable (known as *pyro*) may also be used (as mineral insulated cable can withstand heat more effectively than normal PVC) though more care must be taken with regard to voltage drop on longer runs.

Many lay people in the UK refer to any circuit as a *ring* and the term *lighting ring* is often heard from novices. It is not unheard of to see lighting circuits wired as rings of cable (though usually still with a breaker below the cable rating) in DIY installations.

History and use

The ring circuit and the associated BS 1363 plug and socket system were developed in Britain during 1942–1947. They are commonly used in the United Kingdom and to a lesser extent in the Republic of Ireland. They are also found in the United Arab Emirates. It is likely that they are also used in parts of the Commonwealth of Nations, where Britain had design influence in the past.

The ring main came about because Britain had to embark on a massive rebuilding programme following World War II. There was an acute shortage of copper, and it was necessary to devise a scheme that used less copper than would normally be the case. The scheme was specified to use 13 A fused socket outlets, and several designs for the plugs and sockets appeared. Only the square pin (BS 1363) system survives, but the round pin Dorman & Smith system was still in use in many locations well into the 1980s, and is still occasionally seen today. This latter plug had the distinctive feature that the fuse was also the live pin and unscrewed from the plug body.

The ring circuit was devised during a time of copper shortage to allow two 3 kW heaters to be used in any two locations and to allow some power to small appliances, and to keep total copper use low. It has stayed the most common circuit configuration in the UK, although the 20 A radial (essentially breaking each ring in half and putting the halves on a separate breaker) is becoming more common. Splitting a ring into two 20 A radials can be a useful technique where one leg of the ring is damaged and cannot easily be replaced.

Another advantage of ring circuits was an economy of cable and labour, as one could connect a cable between two existing 15 A radially wired sockets to make one 30 A ring, then adding as many sockets as were desired. This was an important consideration in the austerity of the 1940s. This would leave the ring supplied by two 15 A fuses, which worked well enough in practice, even if unconventional.

Many pre-war (round pin) installations used double pole fusing. When two 15 A radials were converted to a ring on these systems, the ring would then be supplied by no fewer than 4 fuses. Such circuits are rare today.

Installation rules

Rules for ring circuits say that the cable rating must be no less than two thirds of the rating of the protective device. This means that the risk of sustained overloading of the cable can be considered minimal. In practice, however, it is extremely uncommon to encounter a ring with a protective device other than a 30 A fuse, 30 A breaker, or 32 A breaker, and a cable size other than those mentioned above.

The IEE Wiring Regulations (BS 7671) permit an unlimited number of socket outlets to be installed on a ring circuit, provided that the floor area served does not exceed 100 m^2. In practice, most small and medium houses have one ring circuit per storey, with larger premises having more.

An installation designer may determine by experience and calculation whether additional circuits are required for areas of high demand; for example, it is common practice to put kitchens on their own ring circuit or sometimes a ring circuit shared with a utility room to avoid putting a heavy load at one point on the main downstairs ring circuit. A heavy concentration of load close together on a ring circuit can cause minor overloading of one of the cables if near the end of the ring, so kitchens should not be wired at one end of a ring circuit.

Unfused spurs from a ring wired in the same cable as the ring are allowed to run one single or double socket from each of the sockets on the ring (the use of two singles was previously allowed but was banned because of people replacing them with doubles) or one fused connection unit (FCU). Spurs may either start from a socket or be joined to the ring cable with a junction box or other approved method of joining cables. Triple and larger sockets are generally fused and therefore can also be placed on a spur.

It is not permitted to have more spurs than sockets on the ring, and it is considered bad practice by most electricians to have spurs in a new installation (some think they are bad practice in all cases).

Where loads other than BS 1363 sockets are connected to a ring circuit or it is desired to place more than one socket for low power equipment on a spur, a BS 1363 fused connection unit (FCU) is used. In the case of fixed appliances this will be a switched fused connection unit (SFCU) to provide a point of isolation for the appliance, but in other cases such as feeding multiple lighting points (putting lighting on a ring through is generally considered bad practice in new installation but is often done when adding lights to an existing property) or multiple sockets, an unswitched one is often preferable.

Fixed appliances with a power rating over 3 kW (for example, water heaters and some electric cookers) or with a non-trivial power demand for long periods (for example, immersion heaters) are no longer recommended to be connected to a ring circuit, but instead are connected to their own dedicated circuit. There are however plenty of older installations with such loads on a ring circuit.

Criticism

The final ring-circuit concept has been criticized in a number of ways, and some of these disadvantages could explain the lack of widespread adoption outside the United Kingdom.

The only way to see the pros and cons of ring circuits is to compare them to the other option: radials.

Fault conditions are not apparent when in use

Ring circuits continue to operate without the user being aware of any problem if there are fault conditions or installation errors that make the circuit unsafe:

- Part of the ring missing or loose connections result in 2.5 mm^2 cables running above rated current at times, resulting in reduced cable life.
    - Radials with a loose connection will overheat severely and be an immediate fire risk.
    - Radials with a broken connection will not function (if L or N broken), or function with no safety earth connection (if E broken).
- Accidental cross connection between two 32 A rings means that the fault current protection reaches 64 A and the required fault disconnection times are violated grossly.
    - Testing at installation addresses this.
- Ring spur installations encourage using three connectors in one terminal, which can cause one to become loose and overheat.
    - The same situation occurs with both radial and ring circuits when branching off is used.

- Rings encourage the installation of too many spurs on a ring, leading to a risk of overheating, especially if spur cables are too long without adequate fusing at the spur-point (i.e. a BS5733 or similar fused spur is not used) - although this is almost certainly a breach of the appropriate wiring code (e.g. BS7671 in the UK).

Complexity of safety tests

Testing ring circuits may take 5–6 times longer than testing radial circuits. The installation tests required for the safe operation of a ring circuit are substantially more time consuming than those for a radial circuit, and DIY installers or electricians qualified in other countries may not be familiar with them.

It is also becoming very apparent that a majority of UK electricians are unfamiliar with the test requirements and, as a result, most ring circuits are not adequately tested, either at first installation or subsequently during the infrequent periodic inspections.

Balancing requirement

Regulation 433-02-04 of BS 7671 requires that the installed load is distributed around the ring such that no part of the cable exceeds its capacity. This requirement is difficult to fulfill and may be largely ignored in practice, as loads are often co-located (washing machine, tumble dryer, dish washer all next to kitchen sink) and not necessarily near the centre of the ring.

Electromagnetic interference

Ring circuits can generate strong unwanted magnetic fields. In a normal (non-ring, radial) circuit, the current flowing in the circuit must return through (almost exactly) the same path through which it came, especially if the live and neutral conductors are kept in close proximity of each other and form a twisted pair. This prevents the circuit forming a large magnetic coil (loop antenna), which would otherwise induce a magnetic field at the AC frequency (50 or 60 Hz).

In a ring circuit, on the other hand, it is possible that the live and neutral currents are not equal on each side of the ring. Mains-frequency currents follow the path of least resistance, and it is possible, especially with aging oxidized contacts, that from a socket, the lowest-resistance *live* connection is along the left-hand side of the ring, and the lowest-resistance *neutral* connection is along the right-hand side. As a result, current is flowing *around* the ring and will therefore induce a magnetic field. In the extreme case of a defect ring circuit, the live connection could become completely interrupted on one side of the ring and the neutral connection on the other, and then the full current would supply the magnetic field. This can lead to substantial electromagnetic interference, such as mains hum in audio devices, accidental triggering of alarm and protection devices (burglar alarms, RCDs, etc.), malfunctions of consumer electronics and medical devices, ground loops, etc.

Overcurrent protection

Ring circuits may not always be adqeuately protected against overcurrents, particularly, as is often the case, if there is an undetected fault, AND the circuit conductors are not sized to match the Overcurrent Protective Device (OPD) as a radial run as opposed to a ring. The purpose of ring circuits is to supply a large number of sockets; therefore, they are protected only with high-rated overcurrent circuit breakers (typically 32 A). In comparison, the radial circuits used in other countries typically supply only a small number of sockets and are therefore protected with lower-rated circuit breakers (typically 10–20 A). As a result, countries using ring circuits find it necessary to add additional lower-rated fuses into the plugs of each appliance. This does create a possible improvement in safety in that an appliance with blown plug fuse will not be live when plugged in again (unless the fuse is first replaced), whereas with fuseless plugs a faulty appliance remains potentially dangerous to plug in, though in most cases it would trip a lower-rated circuit breaker if plugged in again.

This incompatibility in the overcurrent protection of appliance leads between countries using ring and radial circuits has been a major stumbling block on the road to worldwide standardization of domestic AC power plugs and sockets. Although plug-fuses can, in principle, be better matched to the maximum current required by an appliance, in practice, some plugs in the UK are necessarily fitted with a fuse of the maximum permitted rating of 13 A, because a lower-rated device may well operate intermittently due to "surges" (e.g. fit a 3A BS1362 fuse in the plug-top of a fridge, and it will often blow). This is not a problem since all appliances are required to be safe with a 13 A fuse (and in any case, in other EU countries, the appliance concerned is often protected by a 16 A or 20 A OPD for the circuit concerned), but it does mean the potential safety advantage is only partially realised and that the fused plug offers little advantage over an unfused plug used on radial circuit with a 13 A or lower fuse, or B16 or lower circuit breaker. The introduction of regulations in the UK - the Plugs and Sockets (Safety) Regulations - requiring new appliances to be sold with correctly fused pre-fitted plugs improves this situation further.

One theoretical advantage of individually-fused plugs is that a faulty appliance or flexible cord has a high likelihood of blowing only its plug-top fuse, leaving other appliances on the same ring circuit operating. However, with the introduction of EN60898 mcb's and the increased use of RCD protection for general purpose socket outlets in the UK (under BS7671: 2008 and earlier editions of the same standard) means that it is now more likely that the circuit protective device will operate before the plug-top fuse.