

Handbook of Electrical Wiring and Switches



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First Edition, 2012

ISBN 978-81-323-0906-2

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Published by:
Academic Studio
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

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Chapter-1

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 (<i>brass</i>)	white (<i>silver</i>)	green (<i>green</i>)

**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) (<i>brass</i>) brown, orange,	white (120/208/240V) (<i>silver</i>)	green (<i>green</i>) bare conductor green/yellow (isolated)

yellow (277/480V) grey(277/480V) ground)

Canada	red, black (120/208/240V)	white (120/208/240V)	green (<i>green</i>)
	red, black, blue (600/347V)	white (600/347V)	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

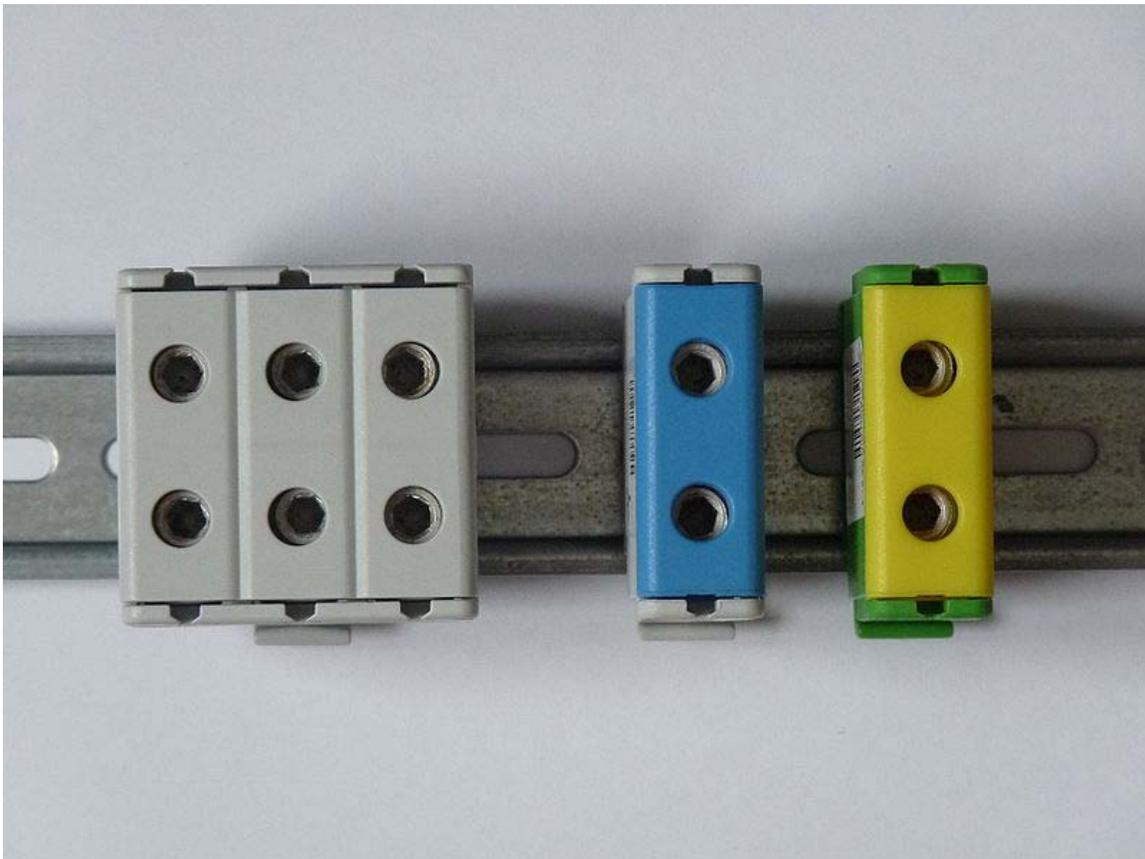
About 1950, PVC insulation and jackets were introduced, especially for residential wiring. About the same time, single conductors with a thinner PVC insulation and a thin nylon jacket became common.

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 mm²) 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.

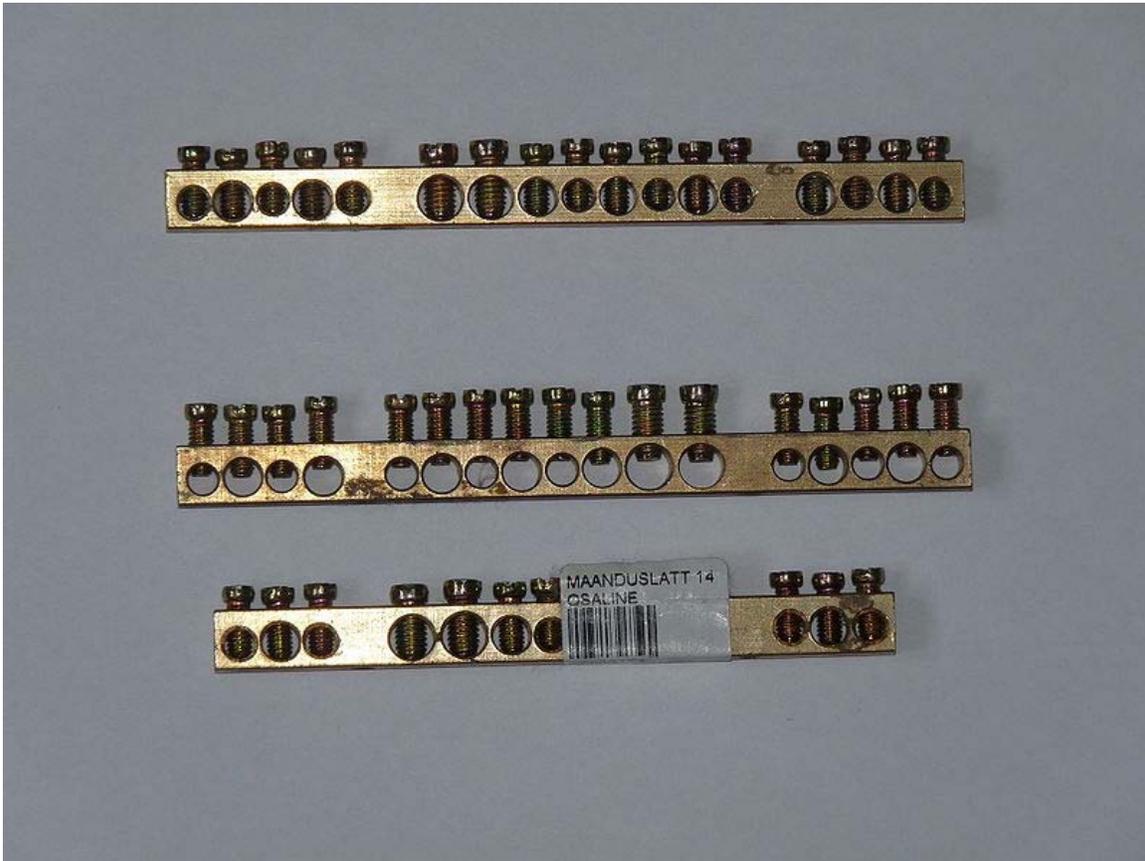
Bus bars, bus duct, cable bus



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



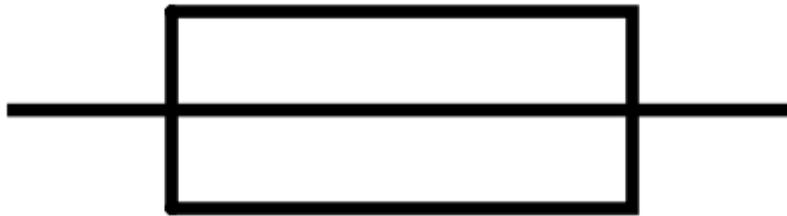
A miniature time-delay fuse used to protect electronic equipment, rated 0.3 amperes at 250 volts. 1.25 inches (about 32 mm) long.



200 A Industrial fuse. 80 kA breaking capacity.



IEC



IEEE/ANSI



IEEE/ANSI

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.

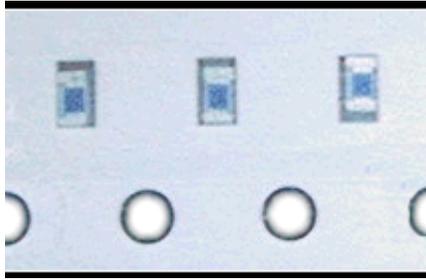
Temperature derating

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 $1.6 \text{ mm} \times 0.79 \text{ mm}$ 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.

FUSEHOLDERS



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:

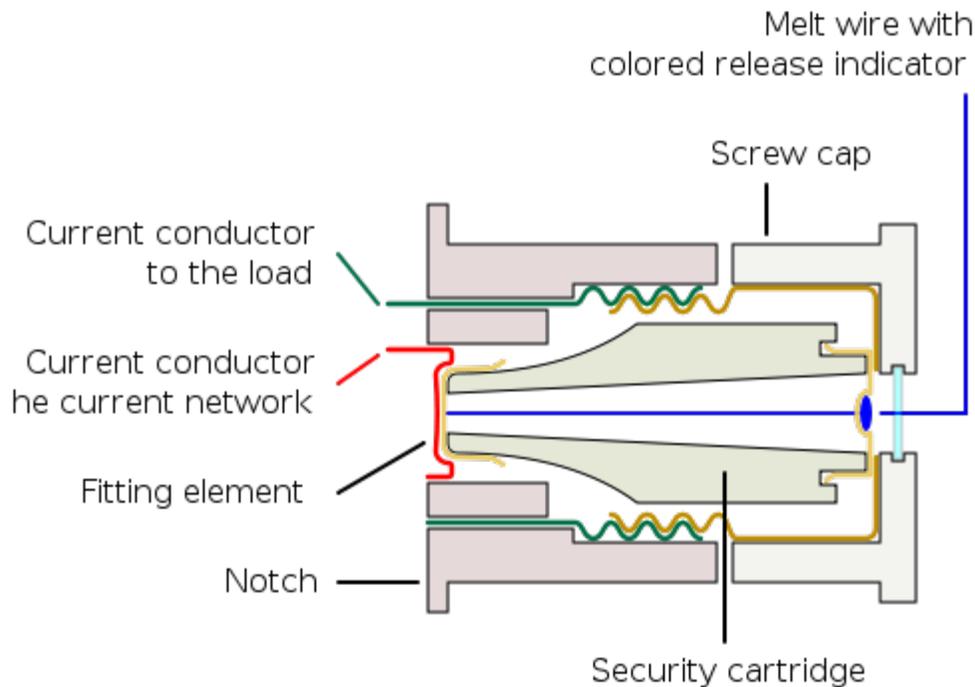
- Indicating pin or striker pin — extends out of the fuse cap when the element is blown.
- Indicating disc — a coloured disc (flush mounted in the end cap of the fuse) falls out when the element is blown.
- Element window — a small window built into the fuse body to provide visual indication of a blown 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.

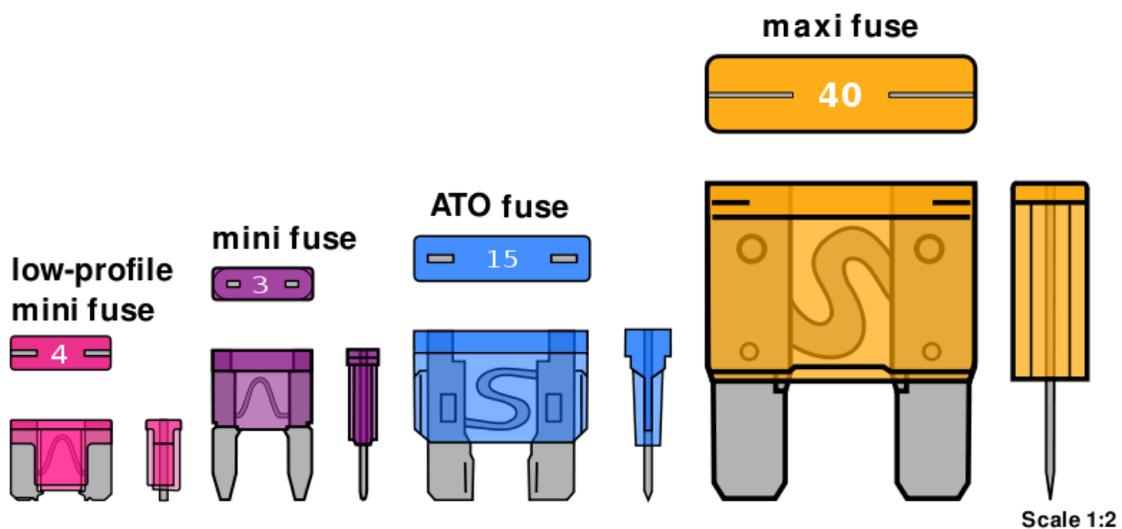
UL 248 fuses (North America)

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

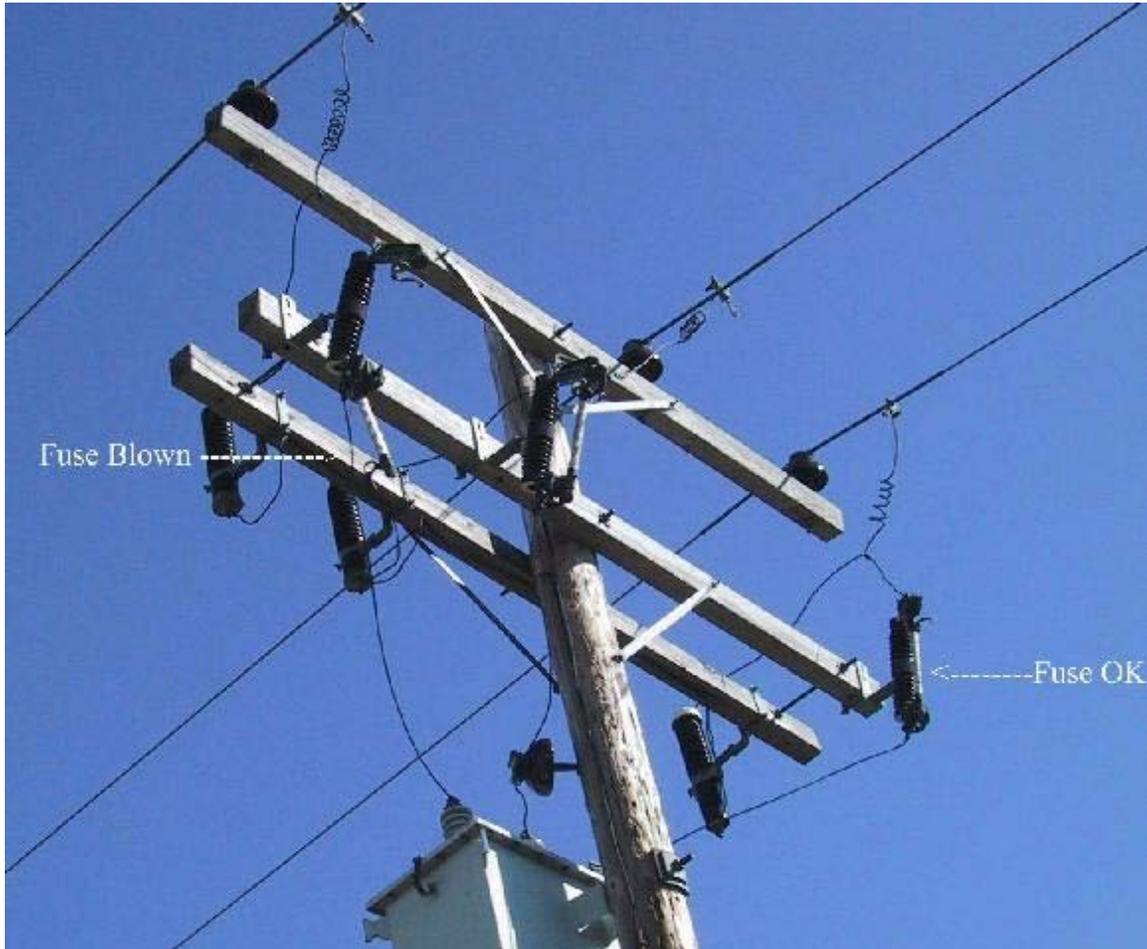
Automotive fuses are used to protect the wiring and electrical equipment for vehicles. There are several different types of automotive fuses and their usage is dependant upon the specific application, voltage, and current demands of the electrical circuit. Automotive fuses can be mounted in fuse blocks, 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 gas-evolving 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.

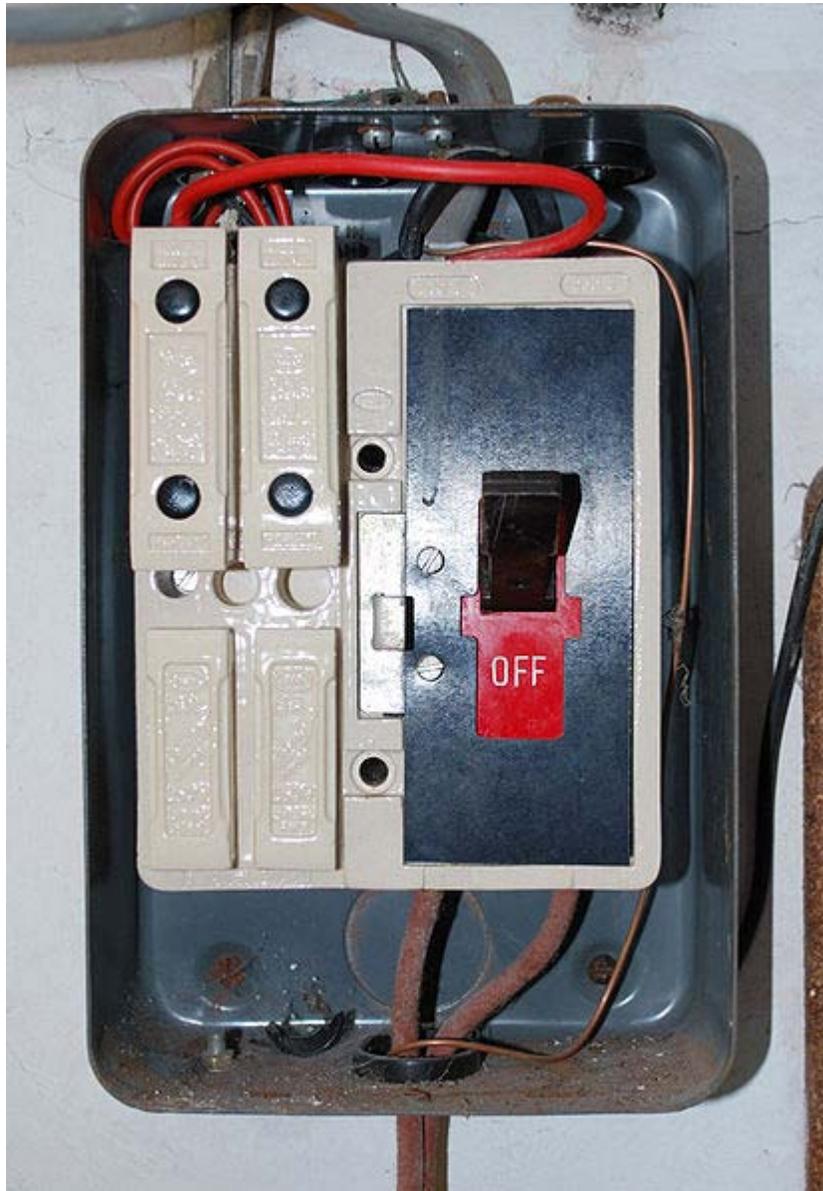
Some types of circuit breakers must be maintained on a regular basis to ensure their mechanical operation during an interruption. This is not the case with fuses, which rely on melting processes where no mechanical operation is required for the fuse to operate under fault conditions.

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.

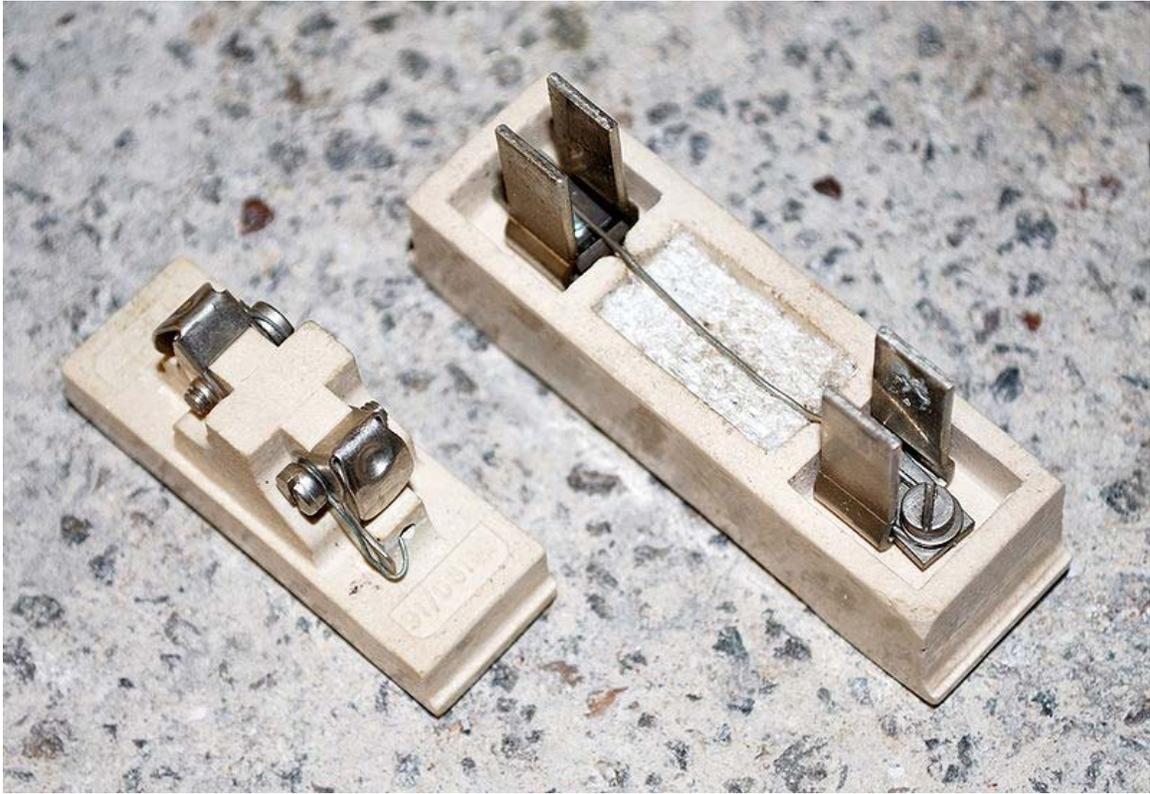
Some manufacturers of medium-voltage distribution fuses combine the overcurrent protection characteristics of the fusible element with the flexibility of relay protection by adding a pyrotechnic device to the fuse operated by external protective relays.

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.

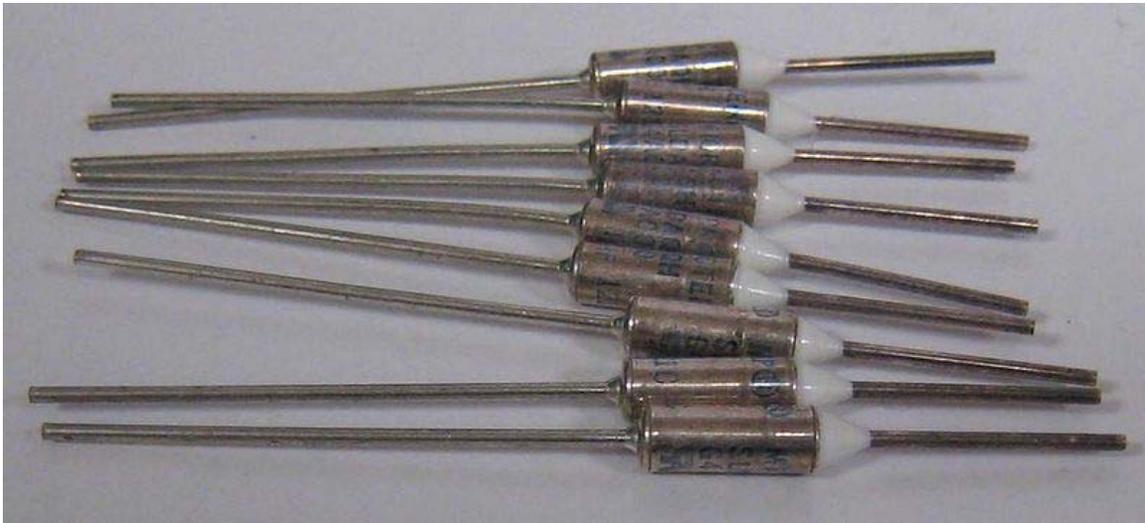
Where the fuses in a system are of similar types, simple rule-of-thumb ratios between ratings of the fuse closest to the load and the next fuse towards the source can be used.

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

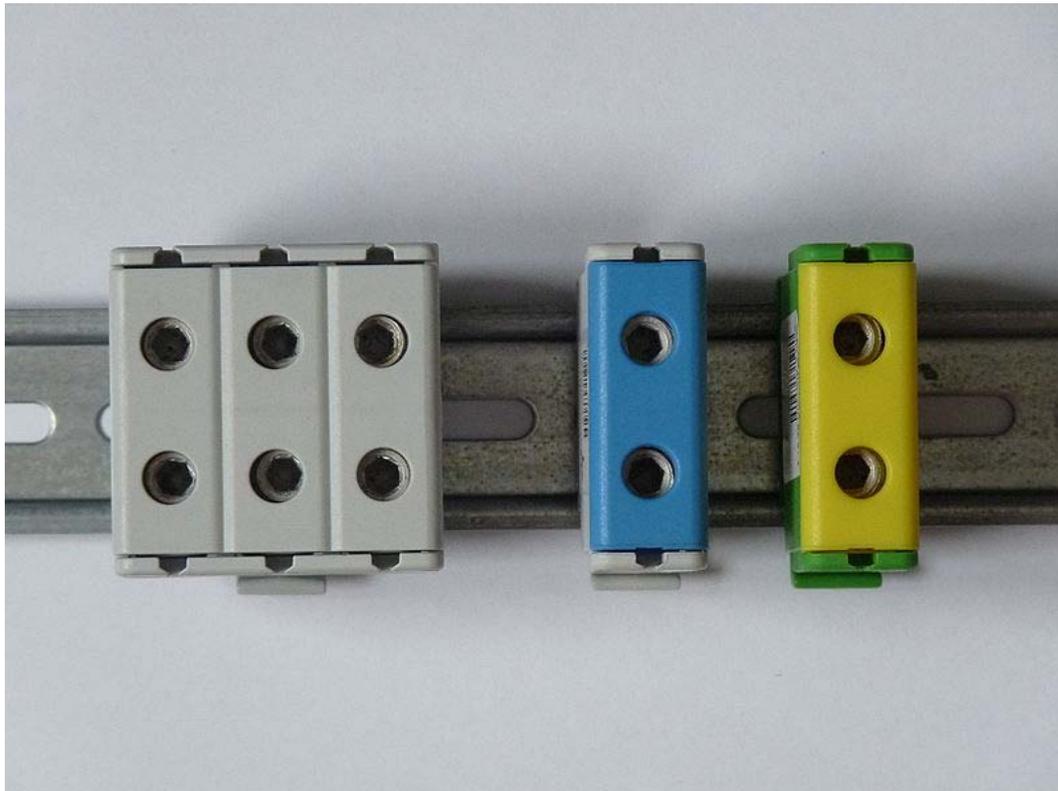
Most metals (with a few exceptions, such as gold) oxidize freely when exposed to air. Aluminium oxide is not an electrical conductor, but rather an electrical insulator. Consequently, the flow of electrons through the oxide layer can be greatly impeded.

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.

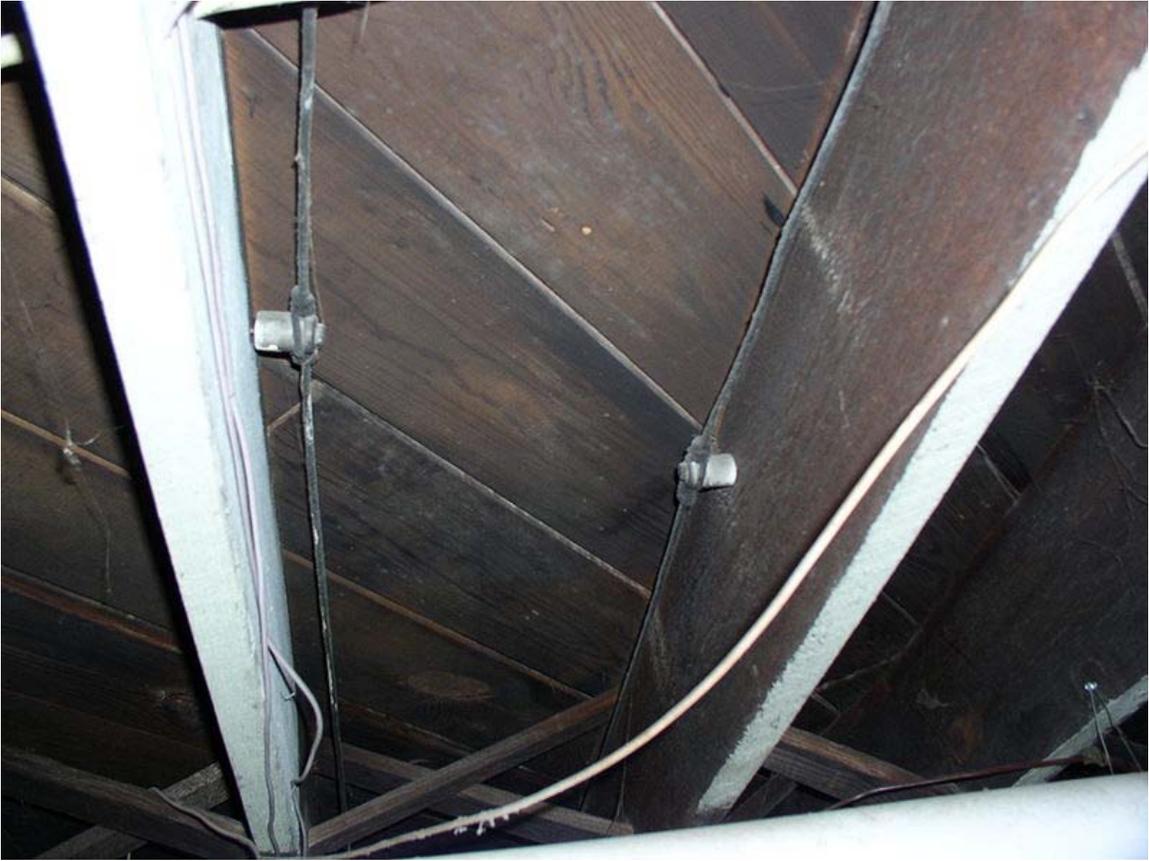
Wiring devices such as light switches, receptacle outlets, and lamp sockets were either surface-mounted, suspended, or flush-mounted within walls and ceilings. Only in the last case were metal boxes always used to enclose the device.



Knob supporting a wire change in direction.



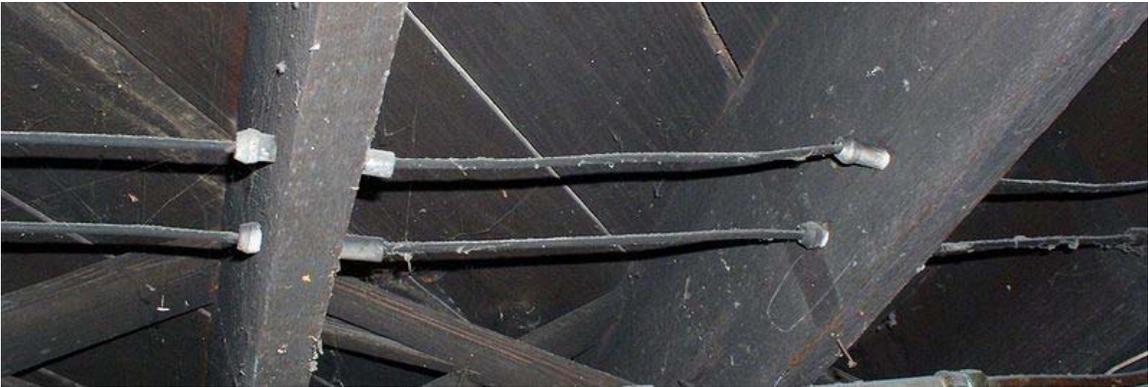
Knob supporting a splice



Knobs supporting long runs of wire



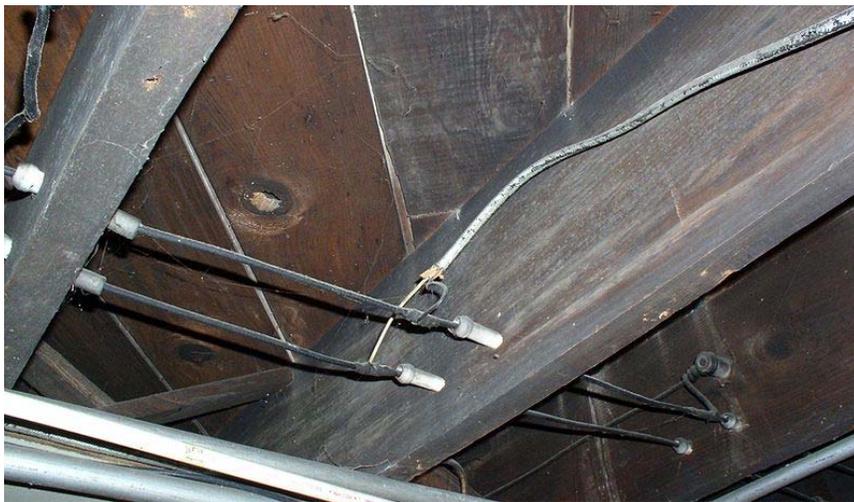
Knobs serving multiple functions



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.

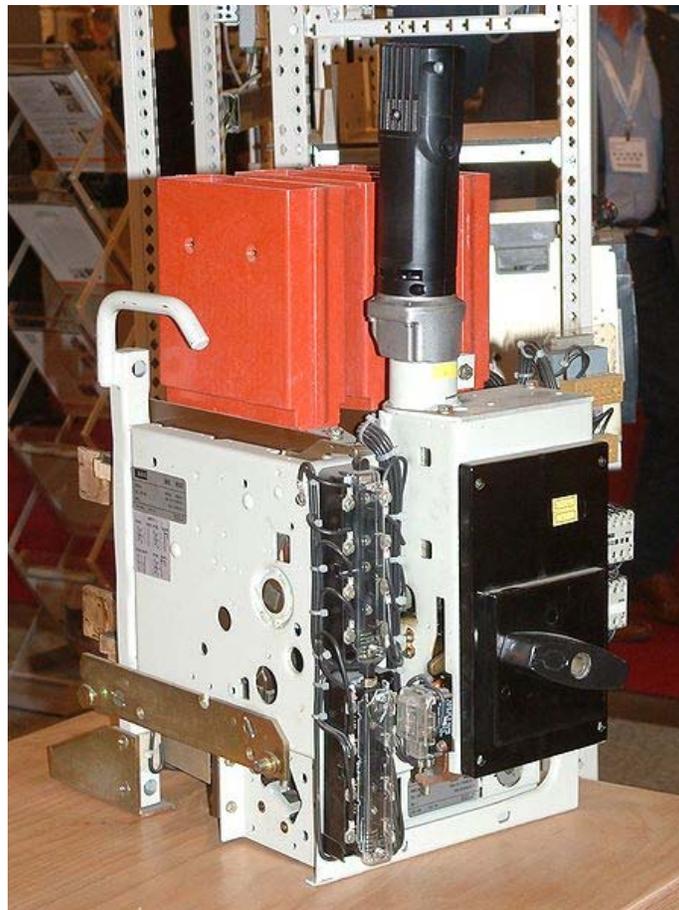
Currently, the United States NEC forbids the use of loose, blown-in, or expanding foam insulation over K&T wiring. This is because K&T is designed to let heat dissipate to the surrounding air. As a result, energy efficiency upgrades that involve insulating previously uninsulated walls usually also require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

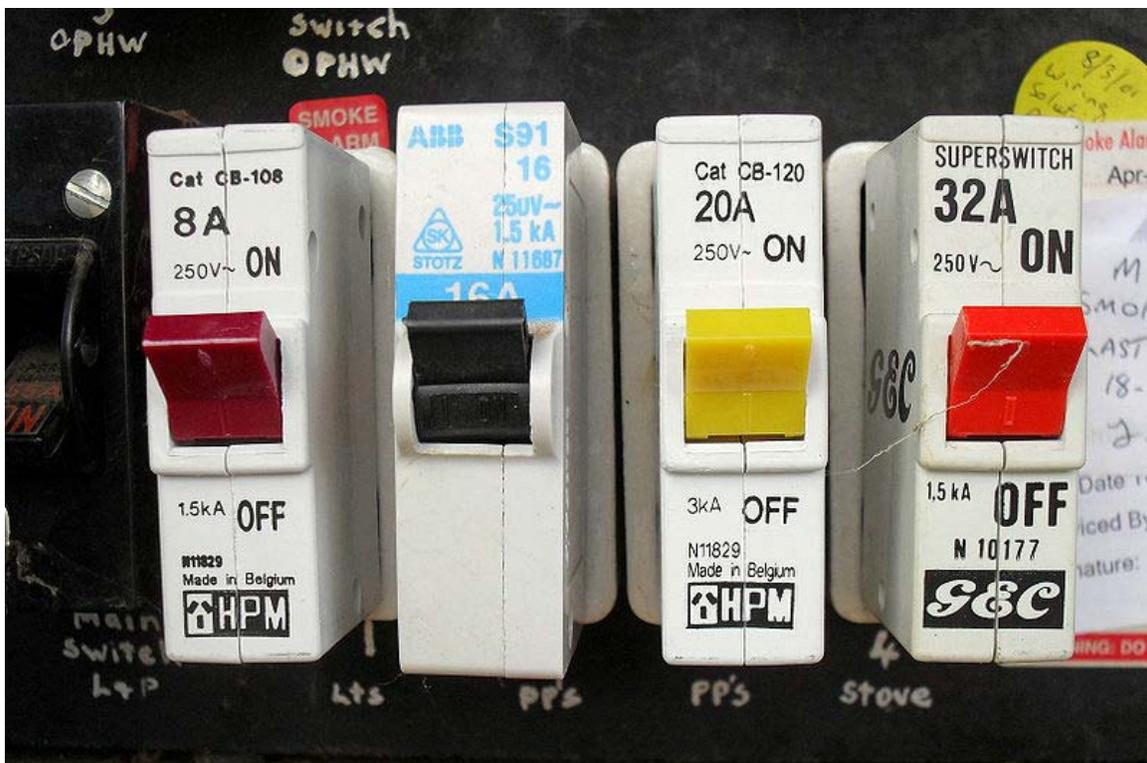
Circuit Breaker



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 (SF₆) 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 above 8 I_n up to and including 12 I_n
K	For the protection of loads that cause frequent short duration (approximately 400 ms to 2 s) current peaks in normal operation. above 2 I_n up to and including 3 I_n for periods in the order of tens of seconds.
Z	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.

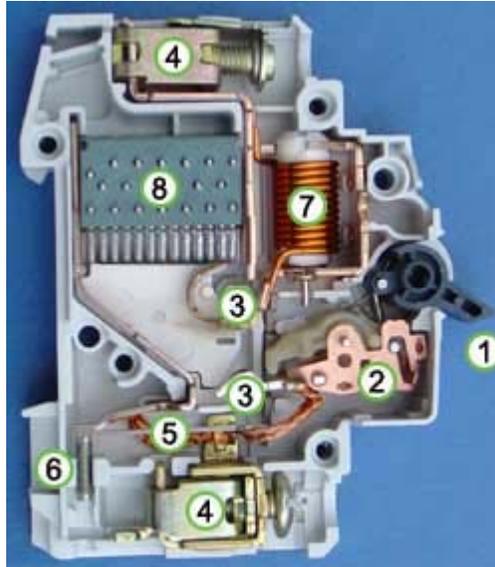


Photo of inside of a circuit breaker

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

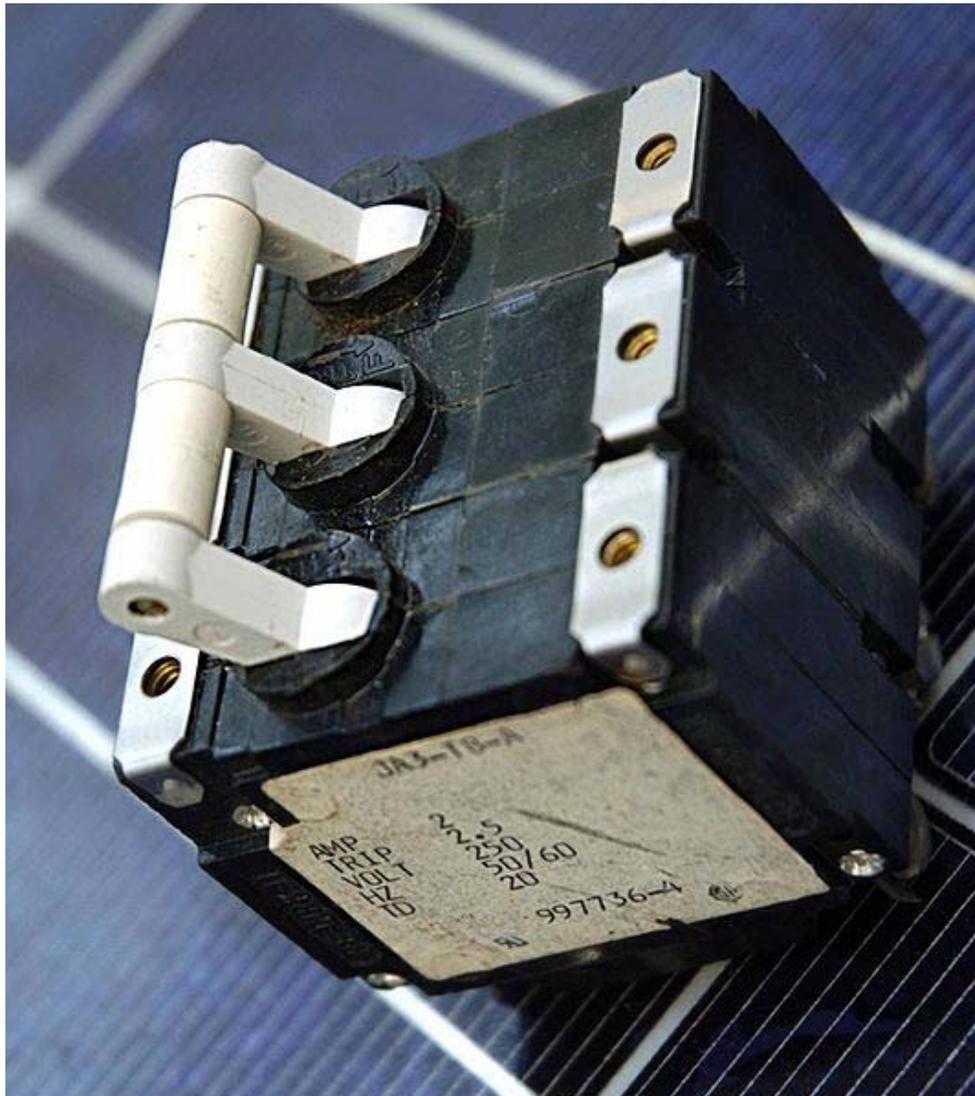
Magnetic circuit breakers use a solenoid (electromagnet) whose pulling force increases with the current. Certain designs utilize electromagnetic forces in addition to those of the solenoid. The circuit breaker contacts are held closed by a latch. As the current in the solenoid increases beyond the rating 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.

- SF₆ 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



115 kV bulk oil circuit breaker



400 kV SF₆ 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
- SF₆

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 SF₆ 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 (SF₆) 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 SF₆ 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 were 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.

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 you 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 your 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 star 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 your 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 outlet. 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 use 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

IPTV is 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. Speaker 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 front 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 where 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. One 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 divided 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 starts 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 solutions. This enables them to be effectively retrofitted into existing homes with the minimum of disruption.

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 disruption is removed. Smart plugs or switches can be used to connect 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.

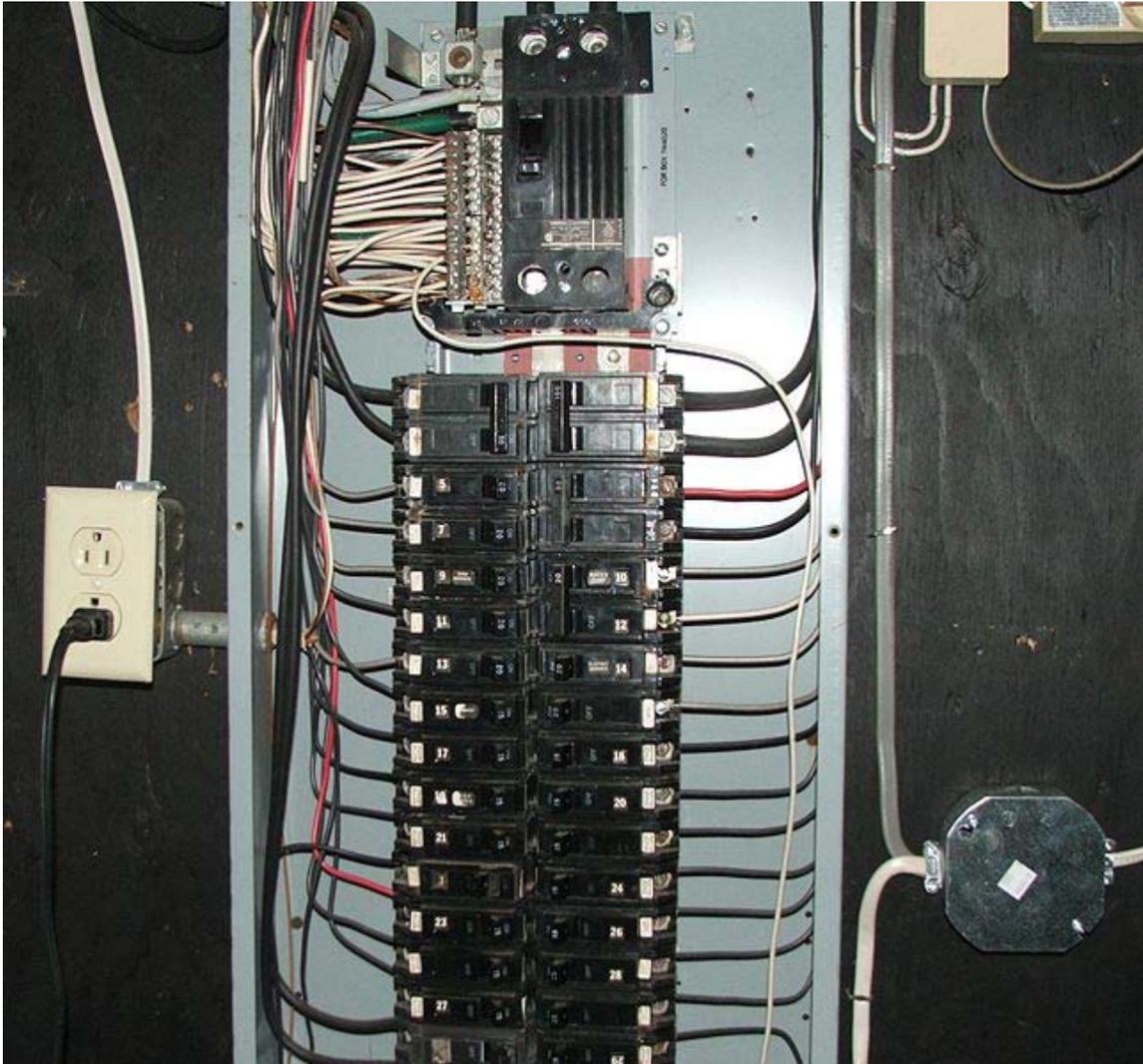
Breakers are usually arranged in two columns. In a US-style board, breaker positions are numbered left-to-right, along each row from top to bottom. This numbering system is universal across various competing manufacturers of breaker panels.

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.

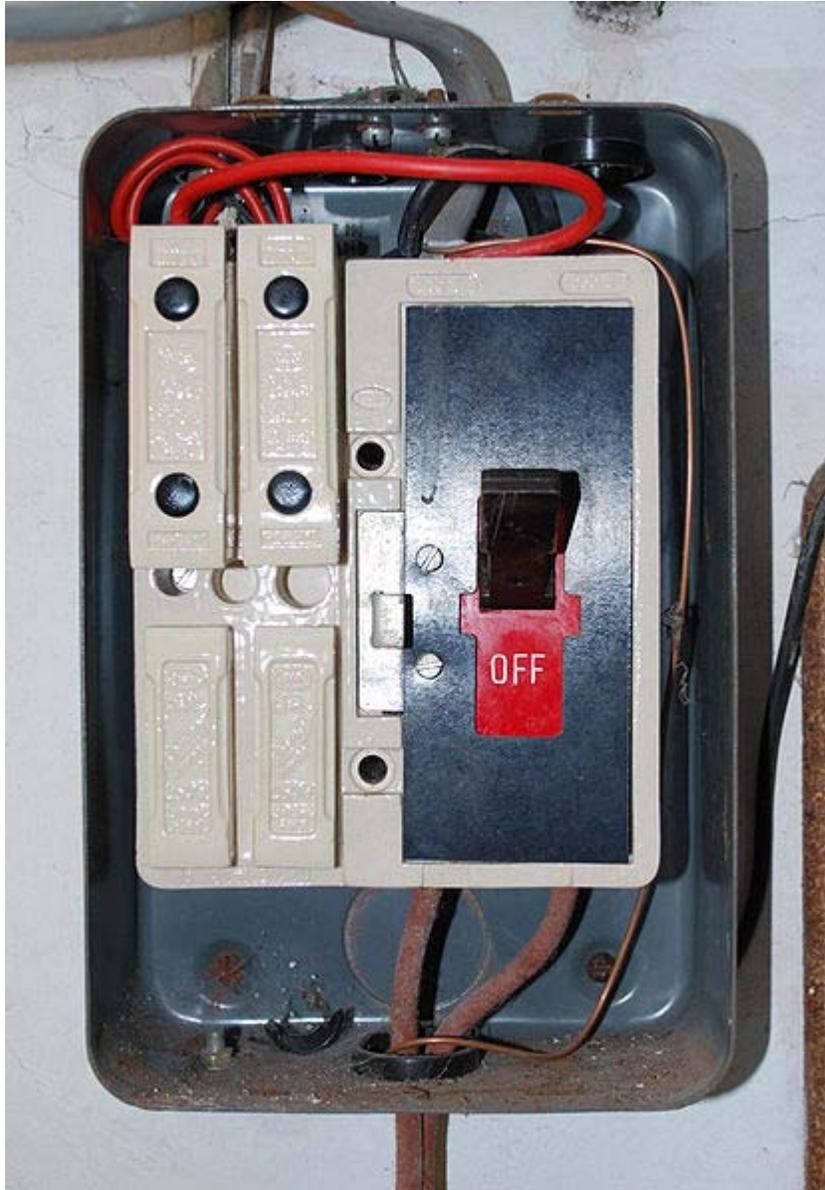
Older CUs

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



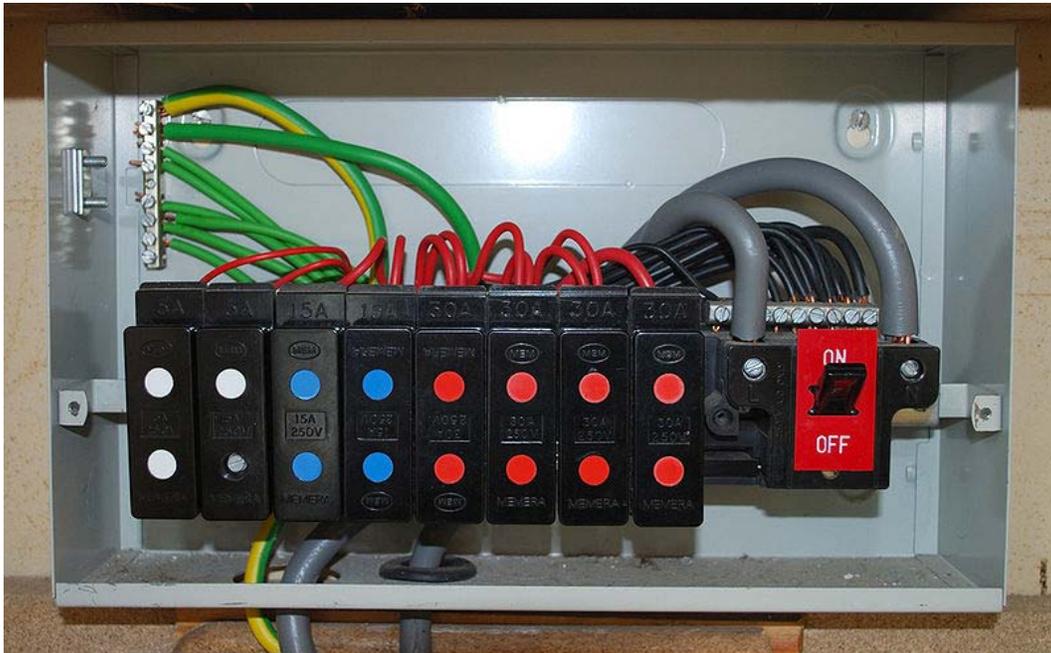
1950s MEM rewirable fuse box (covered)



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.

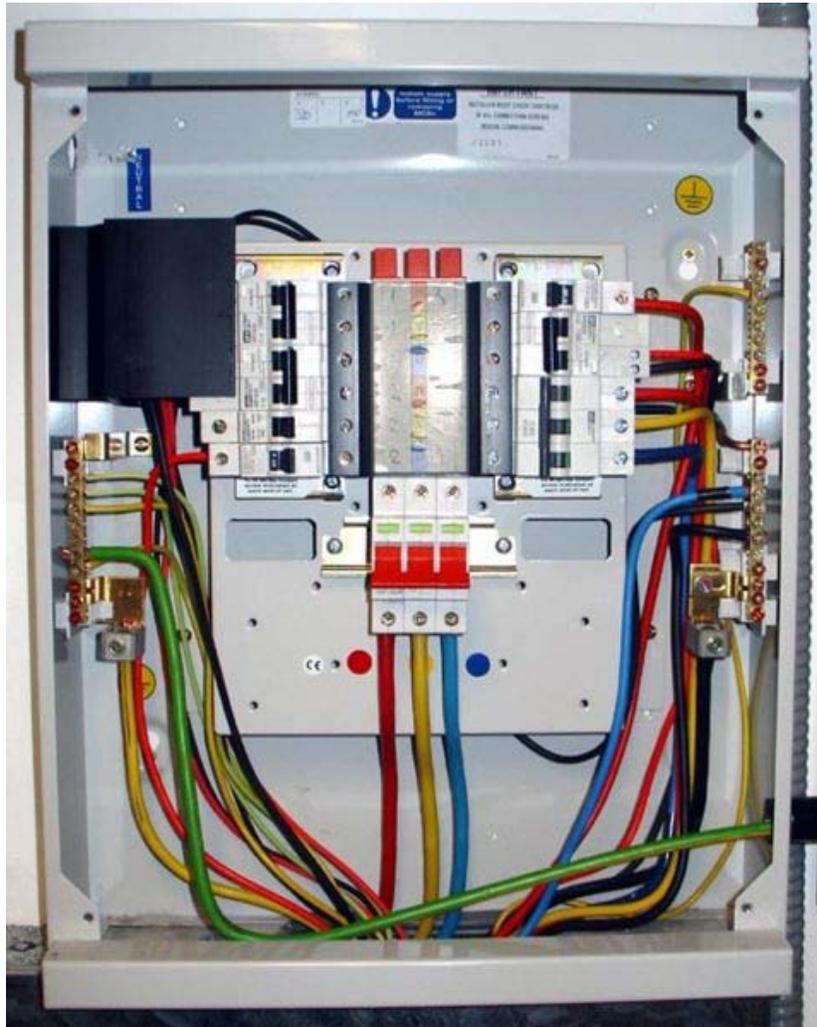
Circuit breaker retrofits

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

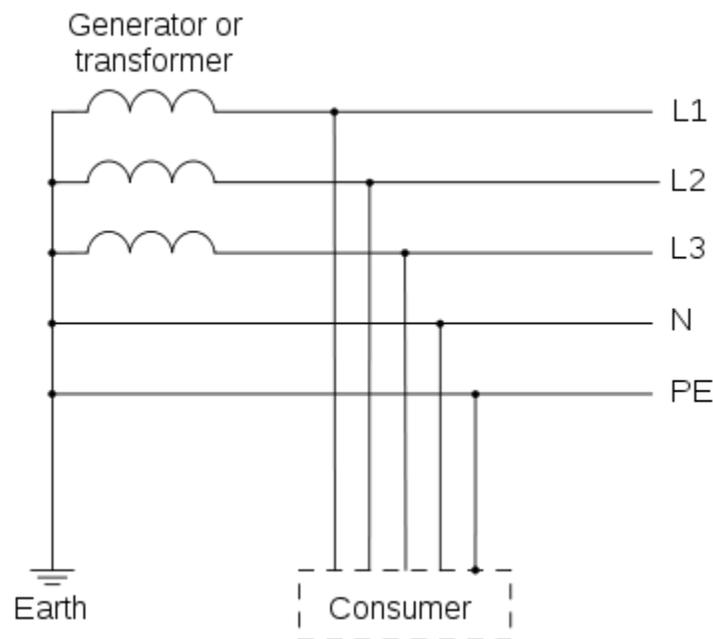
Direct connection of a point with earth

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

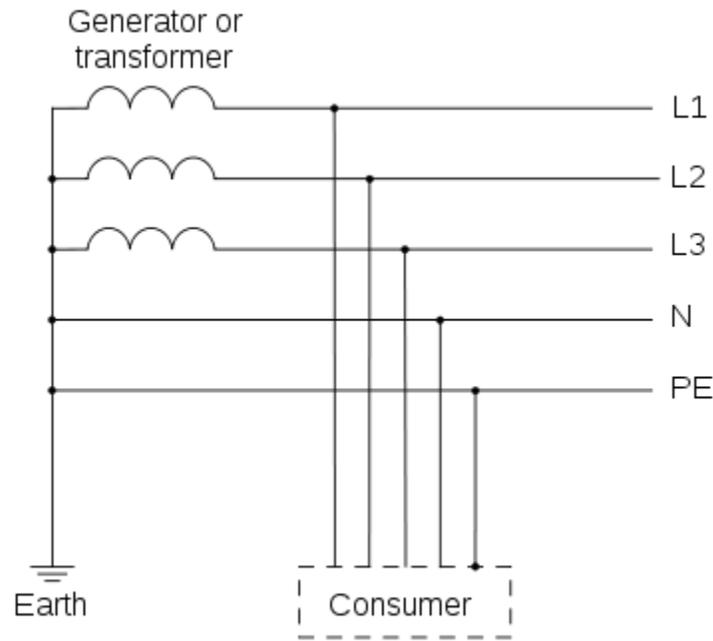
PE and N are separate conductors that are connected together only near the power source.

TN-C

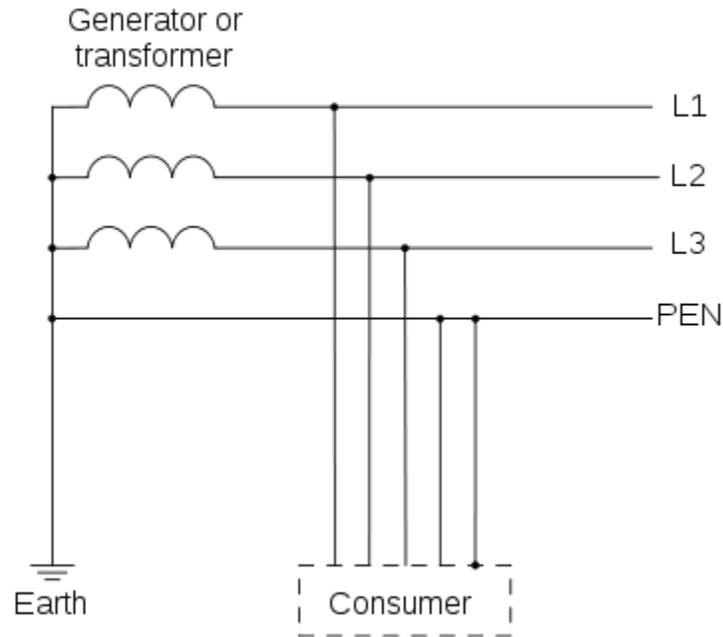
A combined PEN conductor fulfills the functions of both a PE and an N conductor. Rarely used.

TN-C-S

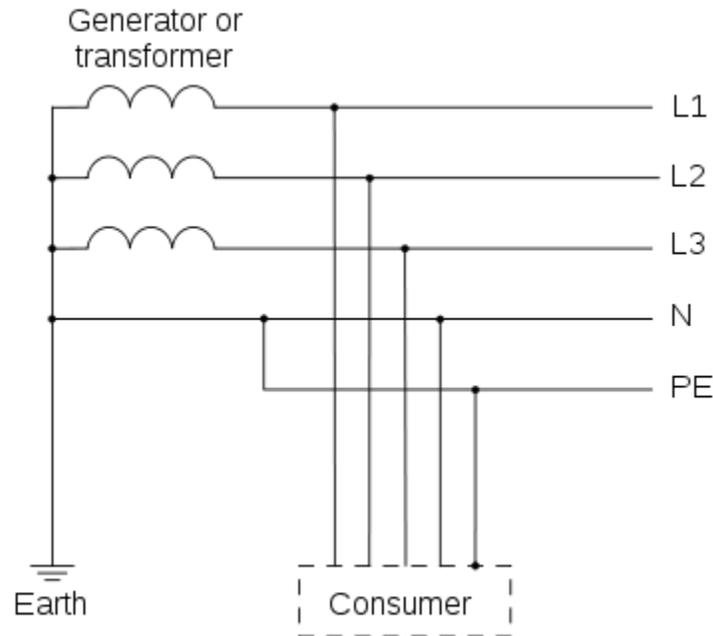
Part of the system uses a combined PEN conductor, which is at some point split up into separate PE and N lines. The combined PEN conductor typically occurs between the substation and the entry point into the building, and separated in the service head. In the UK, this system is also known as *protective 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.

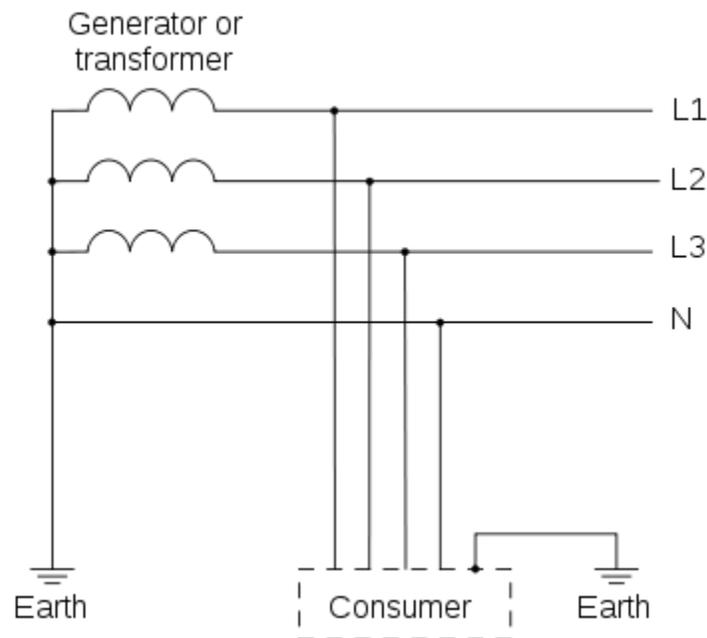
TT network

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.

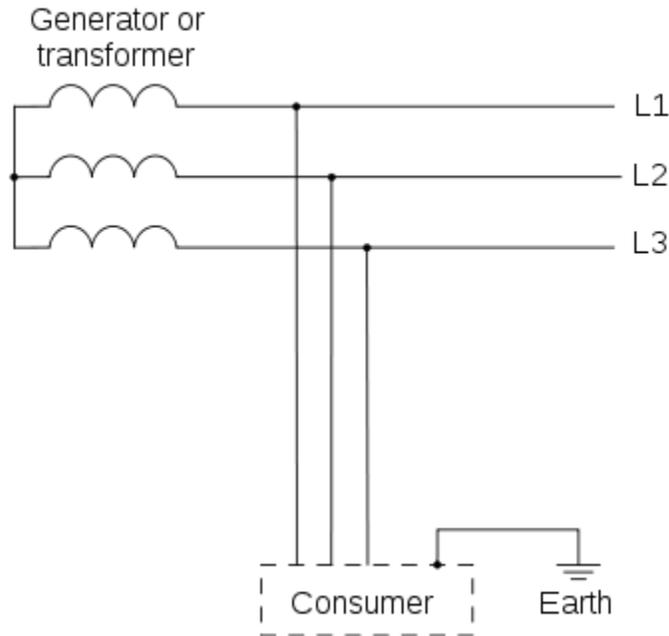
In locations where power is distributed overhead and TT is used, installation earth conductors are not at risk should any overhead distribution conductor be fractured by, say, a fallen tree or branch.

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 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 earthed 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

Switch



Electrical switches. Top, left to right: circuit breaker, mercury switch, wafer switch, DIP switch, surface mount switch, reed switch. Bottom, left to right: wall switch (U.S. style), miniature toggle switch, in-line switch, push-button switch, rocker switch, microswitch.

In electronics, a **switch** is an electrical component that can break an electrical circuit, interrupting the current or diverting it from one conductor to another. The most familiar form of switch is a manually operated electromechanical device with one or more sets of

electrical contacts. Each set of contacts can be in one of two states: either 'closed' meaning the contacts are touching and electricity can flow between them, or 'open', meaning the contacts are separated and nonconducting.

A switch may be directly manipulated by a human as a control signal to a system, such as a computer keyboard button, or to control power flow in a circuit, such as a light switch. Automatically operated switches can be used to control the motions of machines, for example, to indicate that a garage door has reached its full open position or that a machine tool is in a position to accept another workpiece. Switches may be operated by process variables such as pressure, temperature, flow, current, voltage, and force, acting as sensors in a process and used to automatically control a system. For example, a thermostat is a temperature-operated switch used to control a heating process. A switch that is operated by another electrical circuit is called a relay. Large switches may be remotely operated by a motor drive mechanism. Some switches are used to isolate electric power from a system, providing a visible point of isolation that can be pad-locked if necessary to prevent accidental operation of a machine during maintenance, or to prevent electric shock.

In circuit theory

In electronics engineering, an ideal switch describes a switch that:

- has no current limit during its ON state
- has infinite resistance during its OFF state
- has no voltage drop across the switch during its ON state
- has no voltage limit during its OFF state
- has zero rise time and fall time during state changes
- switches only once without "bouncing" between on and off positions

Practical switches have loss and limitation. The ideal switch is often used in circuit analysis as it greatly simplifies the system of equations to be solved, however this can lead to a less accurate solution.

Contacts



A toggle switch in the "on" position.

In the simplest case, a switch has two conductive pieces, often metal, called *contacts* that touch to complete (make) a circuit, and separate to open (break) the circuit. The contact material is chosen for its resistance to corrosion, because most metals form insulating oxides that would prevent the switch from working. Contact materials are also chosen on the basis of electrical conductivity, hardness (resistance to abrasive wear), mechanical strength, low cost and low toxicity.

Sometimes the contacts are plated with noble metals. They may be designed to wipe against each other to clean off any contamination. Nonmetallic conductors, such as conductive plastic, are sometimes used.

Contact terminology



Triple Pole Single Throw (TPST or 3PST) knife switch used to short the windings of a 3 phase wind turbine for braking purposes. Here the switch is shown in the open position.

A pair of contacts is said to be "*closed*" when current can flow from one to the other. When the contacts are separated by an insulating air gap, they are said to be "*open*", and no current can flow between them at normal voltages.

Switches are classified according to the arrangement of their contacts in electronics. Electricians installing building wiring use different nomenclature, such as "*one-way*", "*two-way*", "*three-way*" and "*four-way*" switches, which have different meanings in North American and British cultural regions as described in the table below.

In a push-button type switch, in which the contacts remain in one state unless actuated, the contacts can either be *normally open* (abbreviated "*n.o.*" or "*no*") until closed by operation of the switch, or *normally closed* ("*n.c.*" or "*nc*") and opened by the switch action. A switch with both types of contact is called a *changeover switch*. These may be

"*make-before-break*" which momentarily connect both circuits, or may be "*break-before-make*" which interrupts one circuit before closing the other.

The terms *pole* and *throw* are also used to describe switch contact variations. The number of "*poles*" is the number of separate circuits which are controlled by a switch. For example, a "*2-pole*" switch has two separate identical sets of contacts controlled by the same knob. The number of "*throws*" is the number of separate positions that the switch can adopt. A single-throw switch has one pair of contacts that can either be closed or open. A double-throw switch has a contact that can be connected to either of two other contacts, a triple-throw has a contact which can be connected to one of three other contacts, etc.

These terms give rise to abbreviations for the types of switch which are used in the electronics industry such as "*single-pole, single-throw*" (SPST) (the simplest type, "on or off") or "*single-pole, double-throw*" (SPDT), connecting either of two terminals to the common terminal. In electrical power wiring (i.e. House and building wiring by electricians) names generally involving the suffixed word "*-way*" are used; however, these terms differ between British and American English and the terms *two way* and *three way* are used in both with different meanings.

Electronics specification and abbreviation	Expansion of abbreviation	British mains wiring name	American electrical wiring name	Description	Symbol
SPST	Single pole, single throw	One-way	Two-way	A simple on-off switch: The two terminals are either connected together or disconnected from each other. An example is a light switch.	
SPDT	Single pole, double throw	Two-way	Three-way	A simple changeover switch: C (COM, Common) is connected to L1 or to L2.	
SPCO SPTT, c.o.	Single pole changeover			Similar to SPDT. Some	

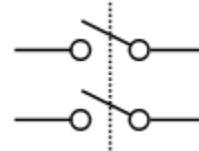
or
 Single pole,
 centre off *or*
 Single Pole,
 Triple Throw

suppliers use
SPCO/SPTT
 for switches
 with a stable
 off position in
 the centre and
SPDT for
 those without.

DPST

Double pole,
 single throw Double pole Double
 pole

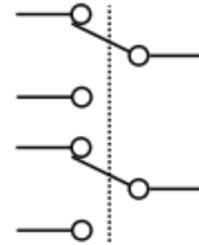
Equivalent to
 two *SPST*
 switches
 controlled by
 a single
 mechanism



DPDT

Double pole,
 double throw

Equivalent to
 two *SPDT*
 switches
 controlled by
 a single
 mechanism: A
 is connected
 to B and D to
 E, or A is
 connected to
 C and D to F.



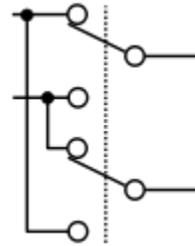
DPCO

Double pole
 changeover
or Double
 pole, centre
 off

Equivalent to
DPDT. Some
 suppliers use
DPCO for
 switches with
 a stable off
 position in the
 centre and
DPDT for
 those without.

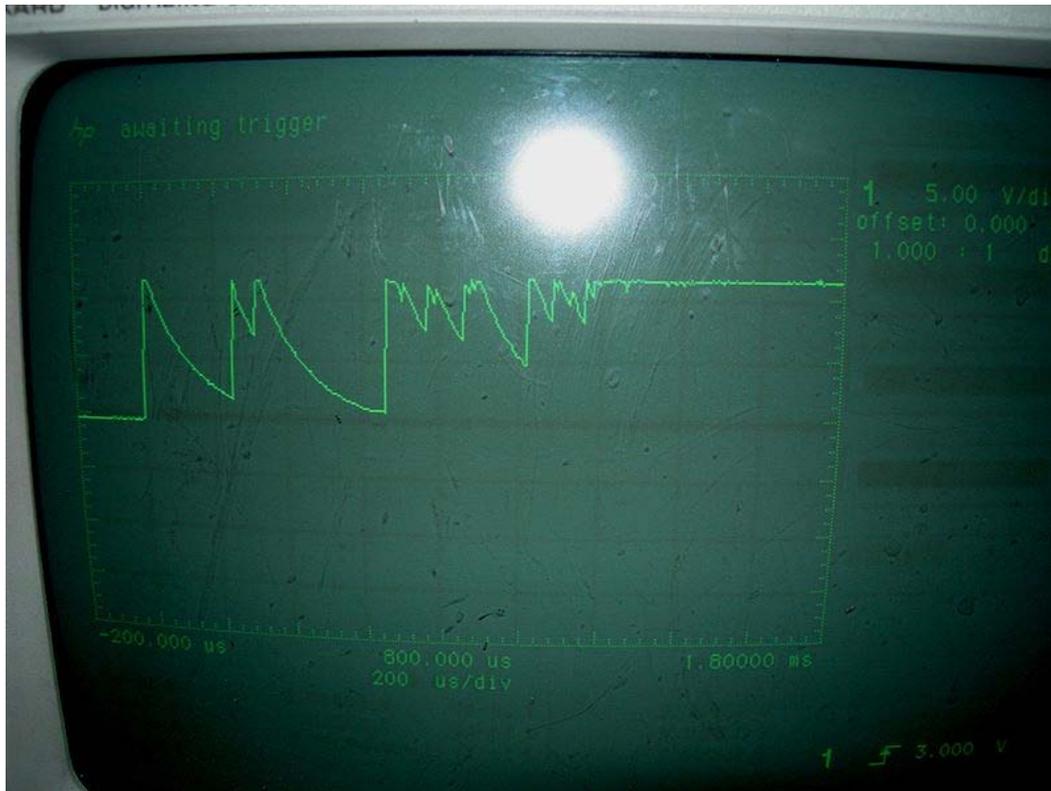
Intermediate Four-way
switch switch

DPDT switch internally wired for polarity-reversal applications: only four rather than six wires are brought outside the switch housing; with the above, B is connected to F and C to E; hence A is connected to B and D to C, or A is connected to C and D to B.



Switches with larger numbers of poles or throws can be described by replacing the "S" or "D" with a number (e.g. 3PST, 4PST, etc.) or in some cases the letter "T" (for "triple"). In the rest the terms *SPST*, *SPDT* and *intermediate* will be used to avoid the ambiguity in the use of the word "way".

Contact bounce



Snapshot of switch bounce on an oscilloscope. The switch bounces between on and off several times before settling.

Contact bounce (also called *chatter*) is a common problem with mechanical switches and relays. Switch and relay contacts are usually made of springy metals that are forced into contact by an actuator. When the contacts strike together, their momentum and elasticity act together to cause bounce. The result is a rapidly pulsed electric current instead of a clean transition from zero to full current. The effect is usually unimportant in power circuits, but causes problems in some analogue and logic circuits that respond fast enough to misinterpret the on-off pulses as a data stream.

The effects of contact bounce can be eliminated by use of mercury-wetted contacts, but these are now infrequently used because of the hazard of mercury release.

Contact circuits can be filtered to reduce or eliminate multiple pulses. In digital systems, multiple samples of the contact state can be taken or a time delay can be implemented so that the contact bounce has settled before the contact input is used to control anything. One way to implement this with an SPDT Switch is by using an SR Latch.

Arcs and quenching

When the power being switched is sufficiently large, the electron flow across opening switch contacts is sufficient to ionize the air molecules across the tiny gap between the contacts as the switch is opened, forming a gas plasma, also known as an electric arc. The plasma is of low resistance and is able to sustain power flow, even with the separation distance between the switch contacts steadily increasing. The plasma is also very hot and is capable of eroding the metal surfaces of the switch contacts.

Where the voltage is sufficiently high, an arc can also form as the switch is closed and the contacts approach. If the voltage potential is sufficient to exceed the breakdown voltage of the air separating the contacts, an arc forms which is sustained until the switch closes completely and the switch surfaces make contact.

In either case, the standard method for minimizing arc formation and preventing contact damage is to use a fast-moving switch mechanism, typically using a spring-operated tipping-point mechanism to assure quick motion of switch contacts, regardless of the speed at which the switch control is operated by the user. Movement of the switch control lever applies tension to a spring until a tipping point is reached, and the contacts suddenly snap open or closed as the spring tension is released.

As the power being switched increases, other methods are used to minimize or prevent arc formation. A plasma is hot and will rise due to convection air currents. The arc can be quenched with a series of nonconductive blades spanning the distance between switch contacts, and as the arc rises its length increases as it forms ridges rising into the spaces between the blades, until the arc is too long to stay sustained and is extinguished. A *puffer* may be used to blow a sudden high velocity burst of gas across the switch contacts, which rapidly extends the length of the arc to extinguish it quickly.

Extremely large switches in excess of 100,000 watts capacity often have switch contacts surrounded by something other than air to more rapidly extinguish the arc. For example, the switch contacts may operate in a vacuum, or immersed in mineral oil.

Power switching

When a switch is designed to switch significant power, the transitional state of the switch as well as the ability to stand continuous operating currents must be considered. When a switch is in the on state its resistance is near zero and very little power is dropped in the contacts; when a switch is in the off state its resistance is extremely high and even less power is dropped in the contacts. However when the switch is flicked the resistance must pass through a state where briefly a quarter (or worse if the load is not purely resistive) of the load's rated power is dropped in the switch.

For this reason, power switches intended to interrupt a load current have spring mechanisms to make sure the transition between on and off is as short as possible regardless of the speed at which the user moves the rocker.

Power switches usually come in two types. A momentary on-off switch (such as on a laser pointer) usually takes the form of a button and only closes the circuit when the button is depressed. A regular on-off switch (such as on a flashlight) has a constant on-off feature. Dual-action switches incorporate both of these features.

Inductive loads

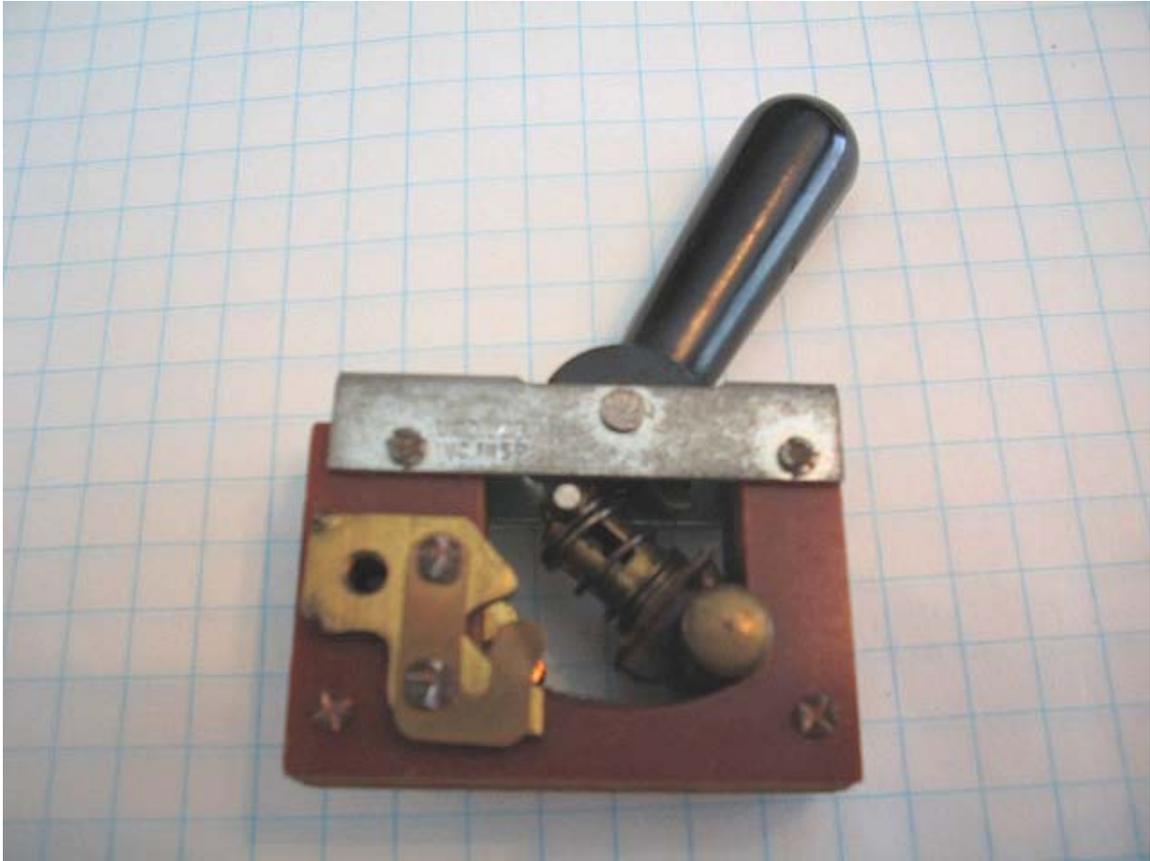
When a strongly inductive load such as an electric motor is switched off, the current cannot drop instantaneously to zero; a spark will jump across the opening contacts. Switches for inductive loads must be rated to handle these cases. The spark will cause electromagnetic interference if not suppressed; a snubber network of a resistor and capacitor in series will quell the spark.

Actuator

The moving part that applies the operating force to the contacts is called the *actuator*, and may be a **toggle** or *dolly*, a **rocker**, a **push-button** or any type of mechanical linkage.

Biased switches

The momentary push-button switch is a type of biased switch. The most common type is a "push-to-make" (or normally-open or NO) switch, which makes contact when the button is pressed and breaks when the button is released. Each key of a computer keyboard, for example, is a normally-open "push-to-make" switch. A "push-to-break" (or normally-closed or NC) switch, on the other hand, breaks contact when the button is pressed and makes contact when it is released. An example of a push-to-break switch is a button used to release a door held open by an electromagnet.



Large toggle switch, depicted in circuit 'open' position, electrical contacts to left; background is 1/4" square graph paper

Toggle switch

A toggle switch is a class of electrical switches that are manually actuated by a mechanical lever, handle, or rocking mechanism.

Toggle switches are available in many different styles and sizes, and are used in countless applications. Many are designed to provide, e.g., the simultaneous actuation of multiple sets of electrical contacts, or the control of large amounts of electric current or mains voltages.

The word "toggle" is a reference to a kind of mechanism or joint consisting of two arms, which are almost in line with each other, connected with an elbow-like pivot. However, the phrase "toggle switch" is applied to a switch with a short handle and a positive snap-action, whether it actually contains a toggle mechanism or not. Similarly, a switch where a definitive click is heard, is called a "positive on-off switch".



Bank of toggle switches on a Data General Nova minicomputer front panel

Special types



Opened float switch of a dirty water pump

Switches can be designed to respond to any type of mechanical stimulus: for example, vibration (the *trembler switch*), tilt, air pressure, fluid level (the *float switch*), the turning of a key (*key switch*), linear or rotary movement (the *limit switch* or *microswitch*), or presence of a magnetic field (the *reed switch*).

Mercury tilt switch

The mercury switch consists of a drop of mercury inside a glass bulb with 2 or more contacts. The two contacts pass through the glass, and are connected by the mercury when the bulb is tilted to make the mercury roll on to them.

This type of switch performs much better than the ball tilt switch, as the liquid metal connection is unaffected by dirt, debris and oxidation, it wets the contacts ensuring a very low resistance bounce-free connection, and movement and vibration do not produce a poor contact. These types can be used for precision works.

It can also be used where arcing is dangerous (such as in the presence of explosive vapour) as the entire unit is sealed.

Knife switch

Knife switches consist of a flat metal blade, hinged at one end, with an insulating handle for operation, and a fixed contact. When the switch is closed, current flows through the hinged pivot and blade and through the fixed contact. Such switches are usually not enclosed. The knife and contacts are typically formed of copper, steel, or brass, depending on the application. Fixed contacts may be backed up with a spring. Several parallel blades can be operated at the same time by one handle. The parts may be mounted on an insulating base with terminals for wiring, or may be directly bolted to an insulated switch board in a large assembly. Since the electrical contacts are exposed, the switch is used only where people cannot accidentally come in contact with the switch or where the voltage is so low as to not present a hazard.

Knife switches are made in many sizes from miniature switches to large devices used to carry thousands of amperes. In electrical transmission and distribution, gang-operated switches are used in circuits up to the highest voltages.

The disadvantages of the knife switch are the slow opening speed and the proximity of the operator to exposed live parts. Metal-enclosed safety disconnect switches are used for isolation of circuits in industrial power distribution. Sometimes spring-loaded auxiliary blades are fitted which momentarily carry the full current during opening, then quickly part to rapidly extinguish the arc.

Footswitch

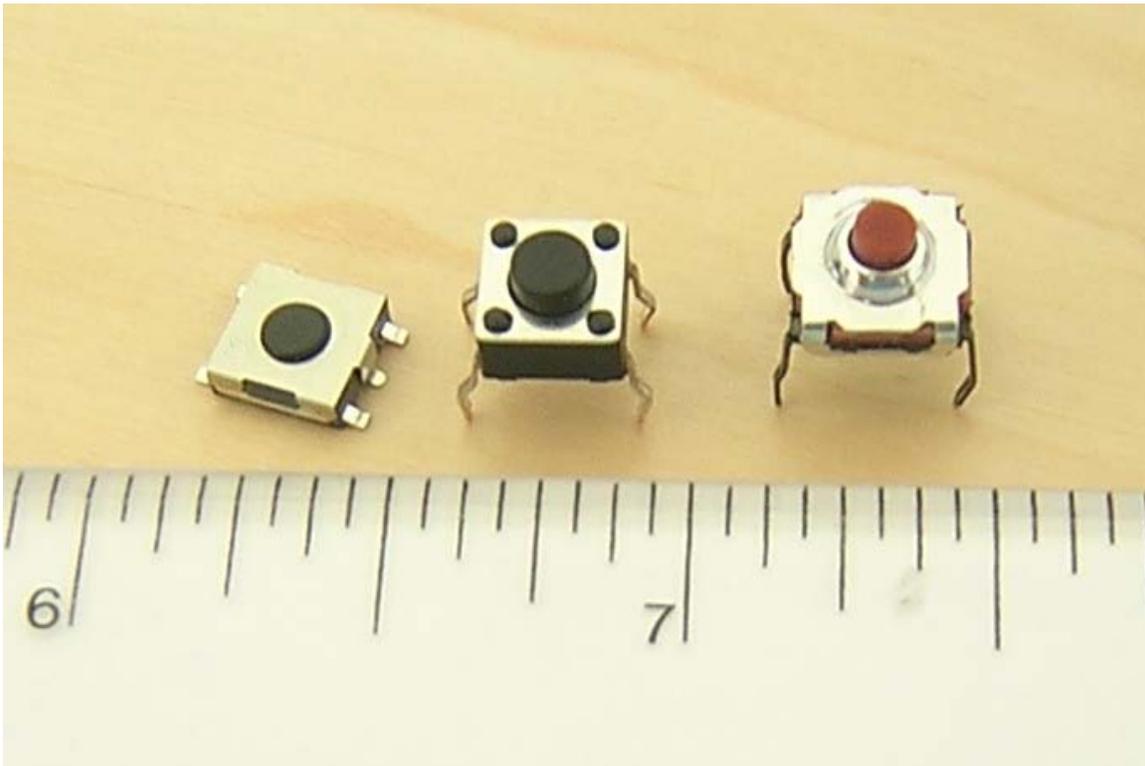
A footswitch is a rugged switch which is operated by foot pressure. An example of use is for the control of an electric sewing machine.

Reversing switch

A DPDT switch has six connections, but since polarity reversal is a very common usage of DPDT switches, some variations of the DPDT switch are internally wired specifically for polarity reversal. These crossover switches only have four terminals rather than six. Two of the terminals are inputs and two are outputs. When connected to a battery or other DC source, the 4-way switch selects from either normal or reversed polarity. Such switches can also be used as intermediate switches in a multiway switching system for control of lamps by more than two switches.

Light switches

In building wiring, light switches are installed at convenient locations to control lighting and occasionally other circuits. By use of multiple-pole switches, control of a lamp can be obtained from two or more places, such as the ends of a corridor or stairwell.



Three pushbutton switches (Tactile Switches). Major scale is inches.

Electronic switches

A relay is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism mechanically, but other operating principles are also used.

Solid-state relays control power circuits with no moving parts, instead using a semiconductor device to perform switching—often a silicon-controlled rectifier or triac.

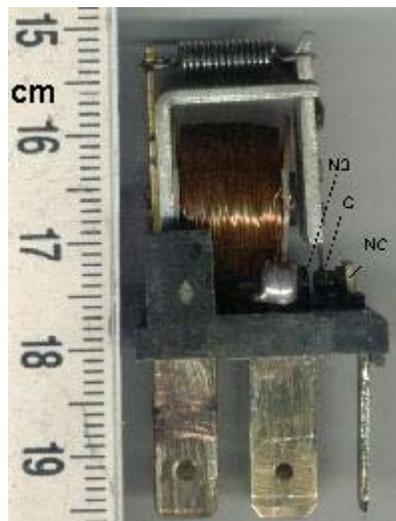
The analogue switch uses two MOSFET transistors in a transmission gate arrangement as a switch that works much like a relay, with some advantages and several limitations compared to an electromechanical relay.

The power transistor(s) in a switching voltage regulator, such as a power supply unit, are used like a switch to alternately let power flow and block power from flowing.

Many people use metonymy to call a variety of devices "switches" that conceptually connect or disconnect signals and communication paths between electrical devices, analogous to the way mechanical switches connect and disconnect paths for electrons to flow between two conductors. Since the advent of digital logic in the 1950s, the term *switch* has spread to a variety of digital active devices such as transistors and logic gates whose function is to change their output state between two logic levels or connect different signal lines, and even computers, network switches, whose function is to provide connections between different ports in a computer network. The term 'switched' is also applied to telecommunications networks, and signifies a network that is circuit switched, providing dedicated circuits for communication between end nodes, such as the public switched telephone network. The common feature of all these usages is they refer to devices that control a binary state: they are either *on* or *off*, *closed* or *open*, *connected* or *not connected*.

Chapter-10

Relay

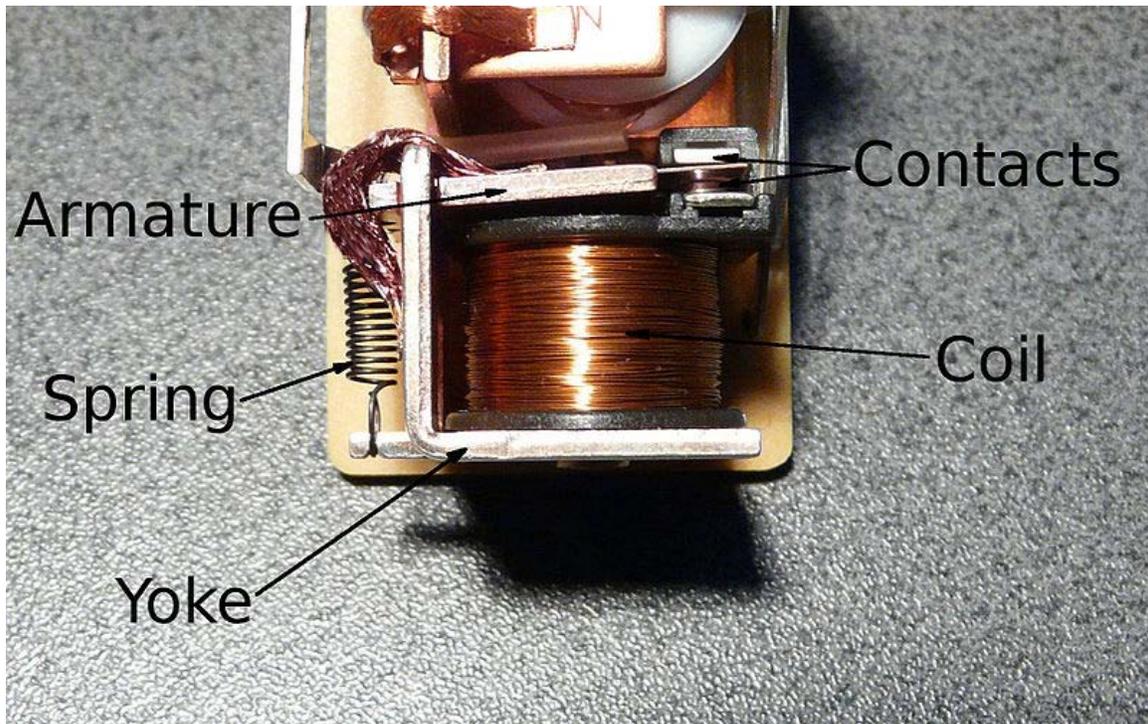


Automotive-style miniature relay, dust cover is taken off

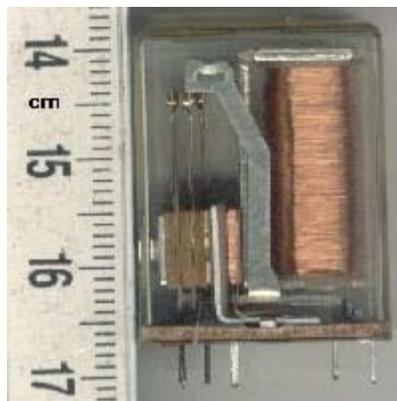
A **relay** is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism mechanically, but other operating principles are also used. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal. The first relays were used in long distance telegraph circuits, repeating the signal coming in from one circuit and re-transmitting it to another. Relays were used extensively in telephone exchanges and early computers to perform logical operations.

A type of relay that can handle the high power required to directly drive an electric motor is called a contactor. Solid-state relays control power circuits with no moving parts, instead using a semiconductor device to perform switching. Relays with calibrated operating characteristics and sometimes multiple operating coils are used to protect electrical circuits from overload or faults; in modern electric power systems these functions are performed by digital instruments still called "protective relays".

Basic design and operation



Simple electromechanical relay



Small relay as used in electronics

A simple electromagnetic relay consists of a coil of wire surrounding a soft iron core, an iron yoke which provides a low reluctance path for magnetic flux, a movable iron armature, and one or more sets of contacts (there are two in the relay pictured). The armature is hinged to the yoke and mechanically linked to one or more sets of moving contacts. It is held in place by a spring so that when the relay is de-energized there is an air gap in the magnetic circuit. In this condition, one of the two sets of contacts in the relay pictured is closed, and the other set is open. Other relays may have more or fewer sets of contacts depending on their function. The relay in the picture also has a wire

connecting the armature to the yoke. This ensures continuity of the circuit between the moving contacts on the armature, and the circuit track on the printed circuit board (PCB) via the yoke, which is soldered to the PCB.

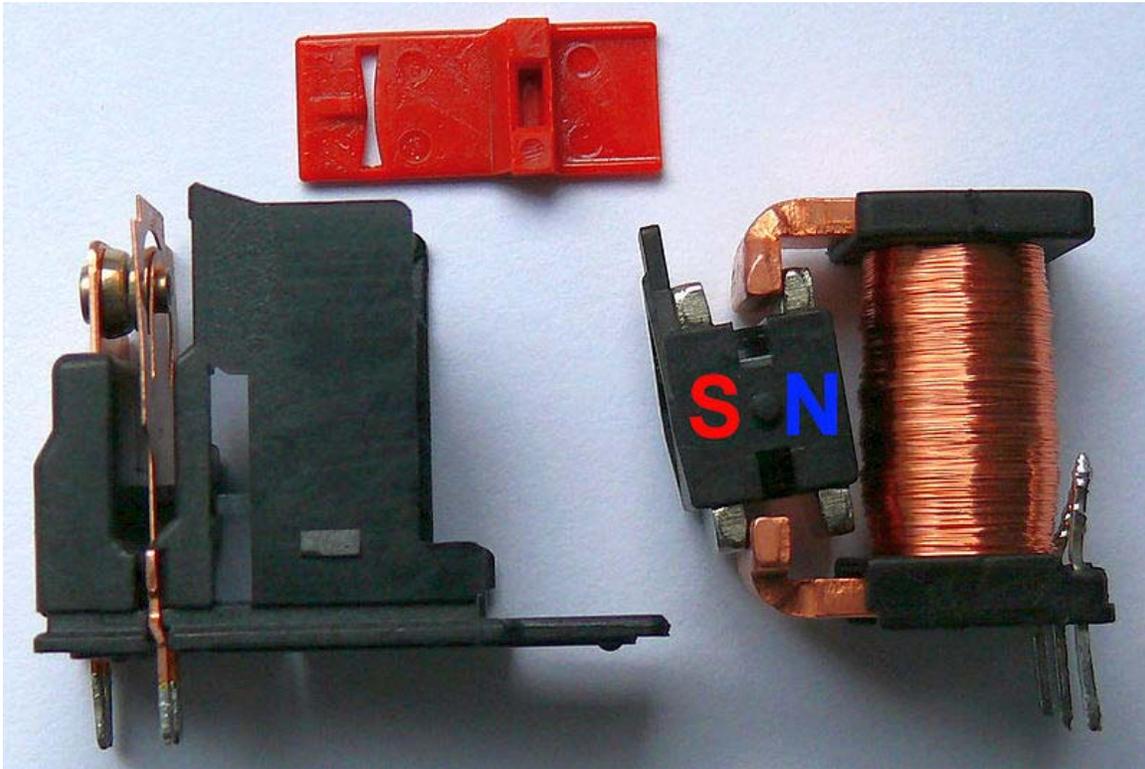
When an electric current is passed through the coil it generates a magnetic field that attracts the armature, and the consequent movement of the movable contact(s) either makes or breaks (depending upon construction) a connection with a fixed contact. If the set of contacts was closed when the relay was de-energized, then the movement opens the contacts and breaks the connection, and vice versa if the contacts were open. When the current to the coil is switched off, the armature is returned by a force, approximately half as strong as the magnetic force, to its relaxed position. Usually this force is provided by a spring, but gravity is also used commonly in industrial motor starters. Most relays are manufactured to operate quickly. In a low-voltage application this reduces noise; in a high voltage or current application it reduces arcing.

When the coil is energized with direct current, a diode is often placed across the coil to dissipate the energy from the collapsing magnetic field at deactivation, which would otherwise generate a voltage spike dangerous to semiconductor circuit components. Some automotive relays include a diode inside the relay case. Alternatively, a contact protection network consisting of a capacitor and resistor in series (snubber circuit) may absorb the surge. If the coil is designed to be energized with alternating current (AC), a small copper "shading ring" can be crimped to the end of the solenoid, creating a small out-of-phase current which increases the minimum pull on the armature during the AC cycle.

A solid-state relay uses a thyristor or other solid-state switching device, activated by the control signal, to switch the controlled load, instead of a solenoid. An optocoupler (a light-emitting diode (LED) coupled with a photo transistor) can be used to isolate control and controlled circuits.

Types

Latching relay



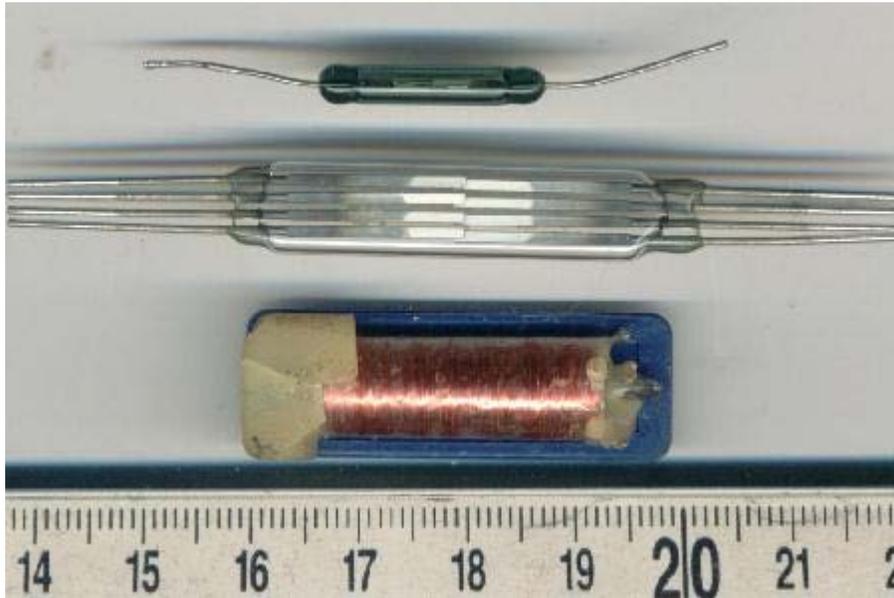
Latching relay with permanent magnet

A *latching relay* has two relaxed states (bistable). These are also called "impulse", "keep", or "stay" relays. When the current is switched off, the relay remains in its last state. This is achieved with a solenoid operating a ratchet and cam mechanism, or by having two opposing coils with an over-center spring or permanent magnet to hold the armature and contacts in position while the coil is relaxed, or with a remanent core. In the ratchet and cam example, the first pulse to the coil turns the relay on and the second pulse turns it off. In the two coil example, a pulse to one coil turns the relay on and a pulse to the opposite coil turns the relay off. This type of relay has the advantage that one coil consumes power only for an instant, while it is being switched, and the relay contacts retain this setting across a power outage. A remanent core latching relay requires a current pulse of opposite polarity to make it change state.

Reed relay

A **reed relay** is a reed switch enclosed in a solenoid. The switch has a set of contacts inside an evacuated or inert gas-filled glass tube which protects the contacts against atmospheric corrosion; the contacts are made of magnetic material that makes them move under the influence of the field of the enclosing solenoid. Reed relays can switch faster than larger relays, require only little power from the control circuit, but have low

switching current and voltage ratings. In addition, the reeds can become magnetized over time, which makes them stick 'on' even when no current is present.



Top, middle: reed switches, bottom: reed relay

Mercury-wetted relay

A **mercury-wetted reed relay** is a form of reed relay in which the contacts are wetted with mercury. Such relays are used to switch low-voltage signals (one volt or less) where the mercury reduces the contact resistance and associated voltage drop, for low-current signals where surface contamination may make for a poor contact, or for high-speed applications where the mercury eliminates contact bounce. Mercury wetted relays are position-sensitive and must be mounted vertically to work properly. Because of the toxicity and expense of liquid mercury, these relays are now rarely used.

Polarized relay

A **polarized relay** placed the armature between the poles of a permanent magnet to increase sensitivity. Polarized relays were used in middle 20th Century telephone exchanges to detect faint pulses and correct telegraphic distortion. The poles were on screws, so a technician could first adjust them for maximum sensitivity and then apply a bias spring to set the critical current that would operate the relay.

Machine tool relay

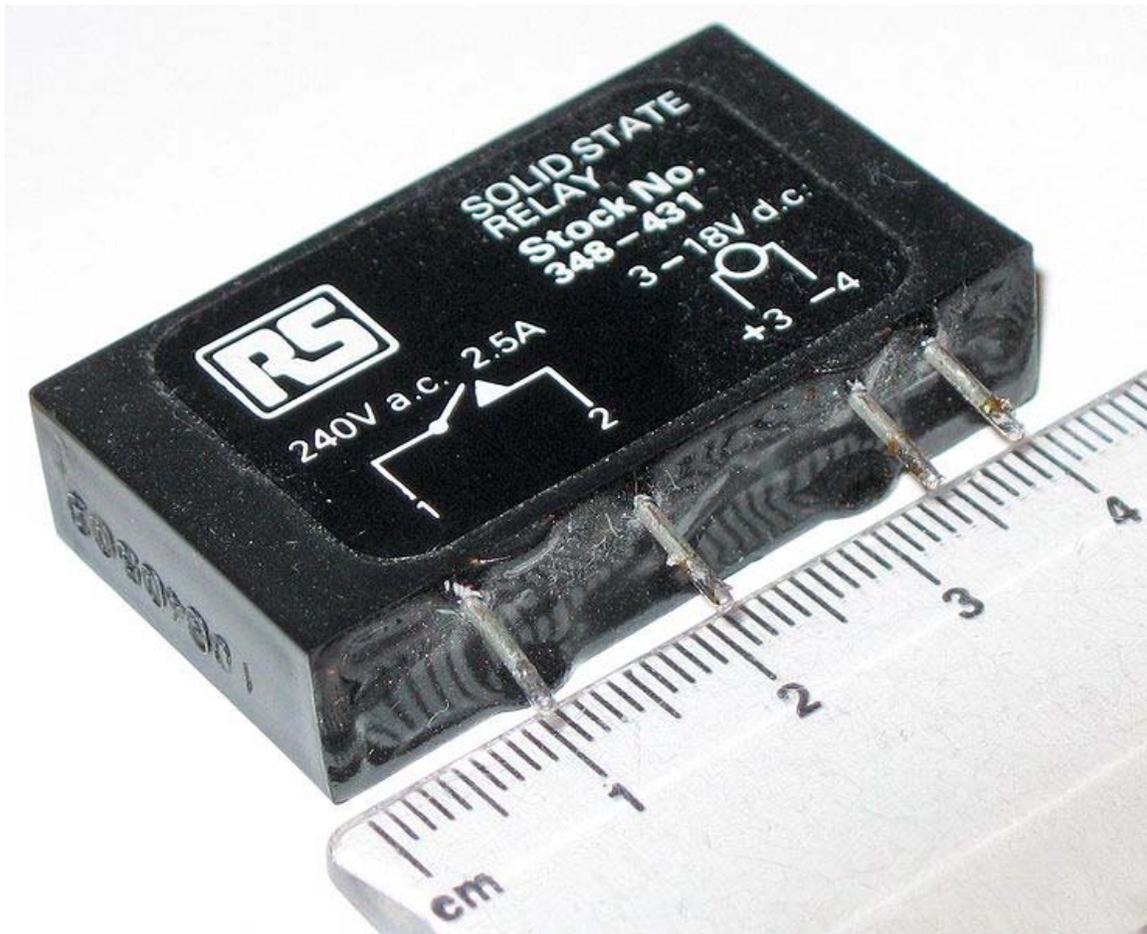
A **machine tool relay** is a type standardized for industrial control of machine tools, transfer machines, and other sequential control. They are characterized by a large number of contacts (sometimes extendable in the field) which are easily converted from normally-open to normally-closed status, easily replaceable coils, and a form factor that

allows compactly installing many relays in a control panel. Although such relays once were the backbone of automation in such industries as automobile assembly, the programmable logic controller (PLC) mostly displaced the machine tool relay from sequential control applications.

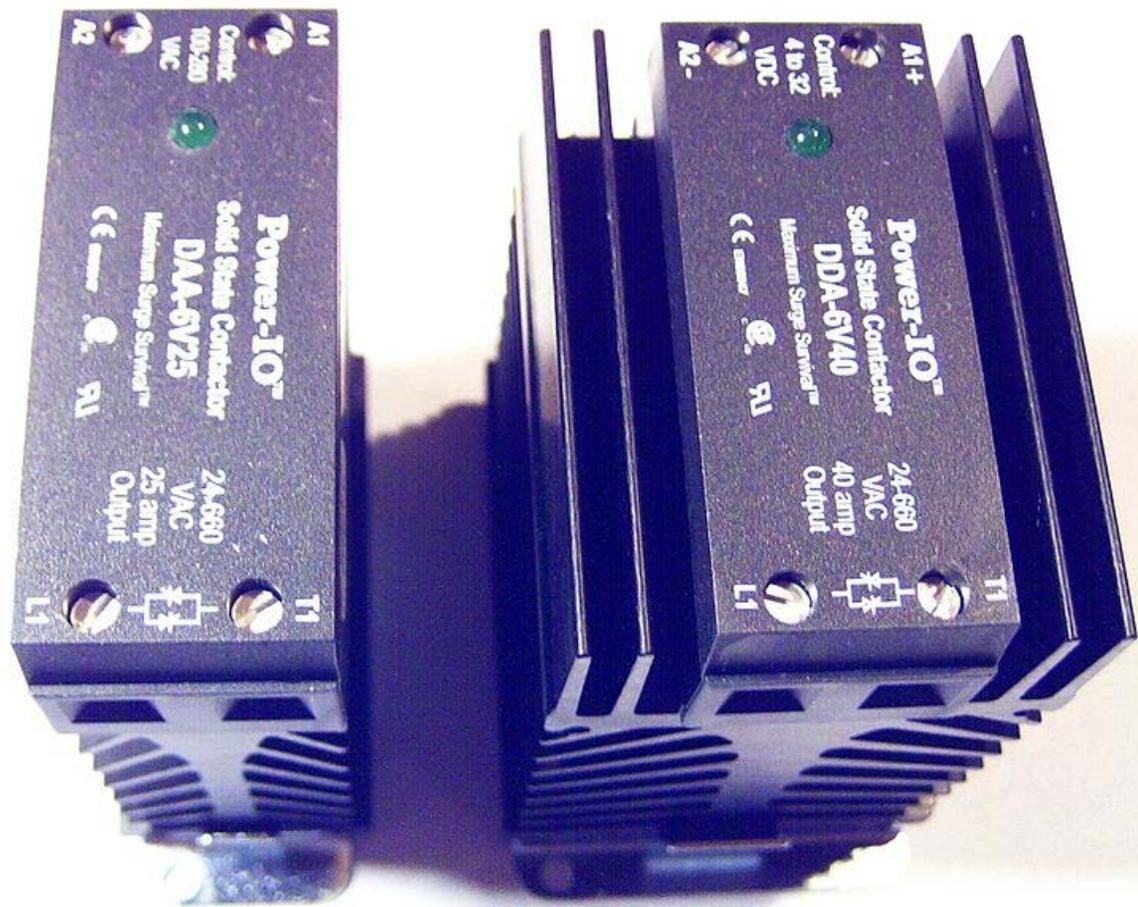
Contactor relay

A **contactor** is a very heavy-duty relay used for switching electric motors and lighting loads, although contactors are not generally called relays. Continuous current ratings for common contactors range from 10 amps to several hundred amps. High-current contacts are made with alloys containing silver. The unavoidable arcing causes the contacts to oxidize; however, silver oxide is still a good conductor. Such devices are often used for motor starters. A motor starter is a contactor with overload protection devices attached. The overload sensing devices are a form of heat operated relay where a coil heats a bi-metal strip, or where a solder pot melts, releasing a spring to operate auxiliary contacts. These auxiliary contacts are in series with the coil. If the overload senses excess current in the load, the coil is de-energized. Contactor relays can be extremely loud to operate, making them unfit for use where noise is a chief concern.

Solid-state relay



Solid state relay, which has no moving parts



25 A or 40 A solid state contactors

A **solid state relay (SSR)** is a solid state electronic component that provides a similar function to an electromechanical relay but does not have any moving components, increasing long-term reliability. With early SSR's, the tradeoff came from the fact that every transistor has a small voltage drop across it. This voltage drop limited the amount of current a given SSR could handle. The minimum voltage drop for such a relay is equal to the voltage drop across one transistor (~0.6-2.0 volts), and is a function of the material used to make the transistor (typically silicon). As transistors improved, higher current SSR's, able to handle 100 to 1,200 Amperes, have become commercially available. Compared to electromagnetic relays, they may be falsely triggered by transients.

Solid state contactor relay

A **solid state contactor** is a heavy-duty solid state relay, including the necessary heat sink, used for switching electric heaters, small electric motors and lighting loads; where frequent on/off cycles are required. There are no moving parts to wear out and there is no contact bounce due to vibration. They are activated by AC control signals or DC control

signals from Programmable logic controller (PLCs), PCs, Transistor-transistor logic (TTL) sources, or other microprocessor and microcontroller controls.

Buchholz relay

A **Buchholz relay** is a safety device sensing the accumulation of gas in large oil-filled transformers, which will alarm on slow accumulation of gas or shut down the transformer if gas is produced rapidly in the transformer oil.

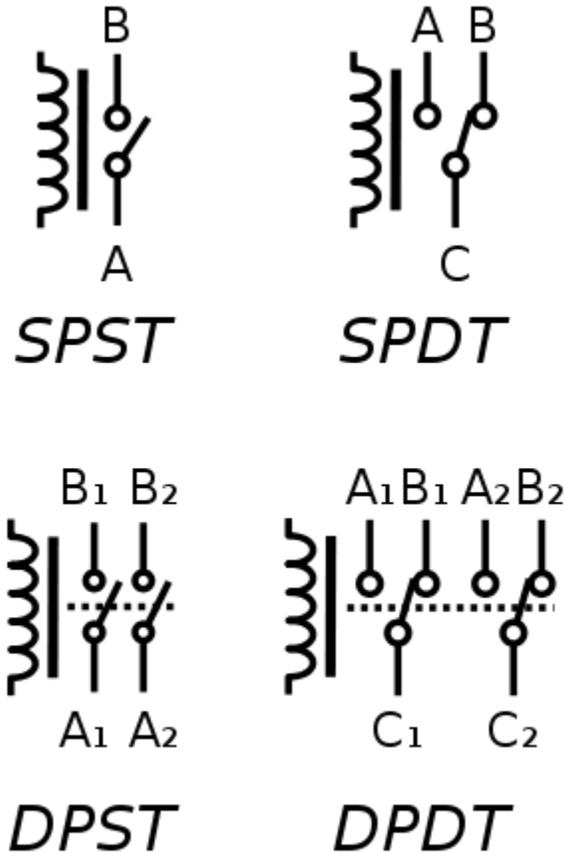
Forced-guided contacts relay

A **forced-guided contacts relay** has relay contacts that are mechanically linked together, so that when the relay coil is energized or de-energized, all of the linked contacts move together. If one set of contacts in the relay becomes immobilized, no other contact of the same relay will be able to move. The function of forced-guided contacts is to enable the safety circuit to check the status of the relay. Forced-guided contacts are also known as "positive-guided contacts", "captive contacts", "locked contacts", or "safety relays".

Overload protection relay

Electric motors need overcurrent protection to prevent damage from over-loading the motor, or to protect against short circuits in connecting cables or internal faults in the motor windings. One type of electric motor overload protection relay is operated by a heating element in series with the electric motor. The heat generated by the motor current heats a bimetallic strip or melts solder, releasing a spring to operate contacts. Where the overload relay is exposed to the same environment as the motor, a useful though crude compensation for motor ambient temperature is provided.

Pole and throw



Circuit symbols of relays. (C denotes the common terminal in SPDT and DPDT types.)

Since relays are switches, the terminology applied to switches is also applied to relays. A relay will switch one or more *poles*, each of whose contacts can be *thrown* by energizing the coil in one of three ways:

- Normally-open (**NO**) contacts connect the circuit when the relay is activated; the circuit is disconnected when the relay is inactive. It is also called a **Form A** contact or "make" contact. **NO** contacts can also be distinguished as "early-make" or **NOEM**, which means that the contacts will close before the button or switch is fully engaged.
- Normally-closed (**NC**) contacts disconnect the circuit when the relay is activated; the circuit is connected when the relay is inactive. It is also called a **Form B** contact or "break" contact. **NC** contacts can also be distinguished as "late-break" or **NCLB**, which means that the contacts will stay closed until the button or switch is fully disengaged.
- Change-over (**CO**), or double-throw (**DT**), contacts control two circuits: one normally-open contact and one normally-closed contact with a common terminal. It is also called a **Form C** contact or "transfer" contact ("break before make"). If

this type of contact utilizes a "make before break" functionality, then it is called a **Form D** contact.

The following designations are commonly encountered:

- **SPST** – Single Pole Single Throw. These have two terminals which can be connected or disconnected. Including two for the coil, such a relay has four terminals in total. It is ambiguous whether the pole is normally open or normally closed. The terminology "SPNO" and "SPNC" is sometimes used to resolve the ambiguity.
- **SPDT** – Single Pole Double Throw. A common terminal connects to either of two others. Including two for the coil, such a relay has five terminals in total.
- **DPST** – Double Pole Single Throw. These have two pairs of terminals. Equivalent to two SPST switches or relays actuated by a single coil. Including two for the coil, such a relay has six terminals in total. The poles may be Form A or Form B (or one of each).
- **DPDT** – Double Pole Double Throw. These have two rows of change-over terminals. Equivalent to two SPDT switches or relays actuated by a single coil. Such a relay has eight terminals, including the coil.

The "S" or "D" may be replaced with a number, indicating multiple switches connected to a single actuator. For example 4PDT indicates a four pole double throw relay (with 14 terminals).

EN 50005 are among applicable standards for relay terminal numbering; a typical EN 50005-compliant SPDT relay's terminals would be numbered 11, 12, 14, A1 and A2 for the C, NC, NO, and coil connections, respectively.

Applications

Relays are used to and for:

- Control a high-voltage circuit with a low-voltage signal, as in some types of modems or audio amplifiers,
- Control a high-current circuit with a low-current signal, as in the starter solenoid of an automobile,
- Detect and isolate faults on transmission and distribution lines by opening and closing circuit breakers (protection relays),



A DPDT AC coil relay with "ice cube" packaging

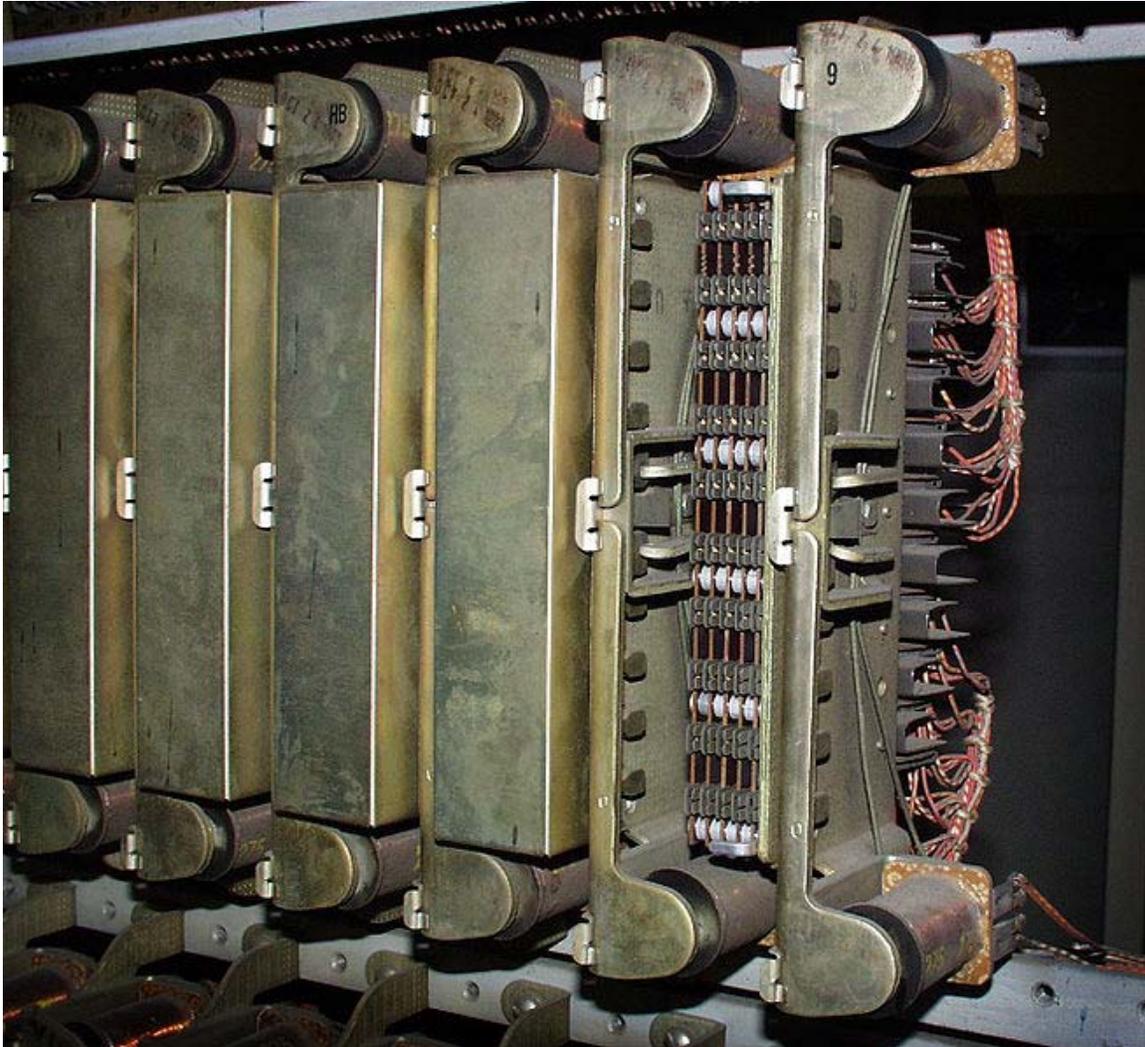
- Isolate the controlling circuit from the controlled circuit when the two are at different potentials, for example when controlling a mains-powered device from a low-voltage switch. The latter is often applied to control office lighting as the low voltage wires are easily installed in partitions, which may be often moved as needs change. They may also be controlled by room occupancy detectors in an effort to conserve energy,
- Logic functions. For example, the boolean AND function is realised by connecting normally open relay contacts in series, the OR function by connecting normally open contacts in parallel. The change-over or Form C contacts perform the XOR (exclusive or) function. Similar functions for NAND and NOR are accomplished using normally closed contacts. The Ladder programming language is often used for designing relay logic networks.
 - Early computing. Before vacuum tubes and transistors, relays were used as logical elements in digital computers.

- Safety-critical logic. Because relays are much more resistant than semiconductors to nuclear radiation, they are widely used in safety-critical logic, such as the control panels of radioactive waste-handling machinery.
- Time delay functions. Relays can be modified to delay opening or delay closing a set of contacts. A very short (a fraction of a second) delay would use a copper disk between the armature and moving blade assembly. Current flowing in the disk maintains magnetic field for a short time, lengthening release time. For a slightly longer (up to a minute) delay, a dashpot is used. A dashpot is a piston filled with fluid that is allowed to escape slowly. The time period can be varied by increasing or decreasing the flow rate. For longer time periods, a mechanical clockwork timer is installed.

Relay application considerations



A large relay with two coils and many sets of contacts, used in an old telephone switching system.



Several 30-contact relays in "Connector" circuits in mid 20th century 1XB switch and 5XB switch telephone exchanges; cover removed on one

Selection of an appropriate relay for a particular application requires evaluation of many different factors:

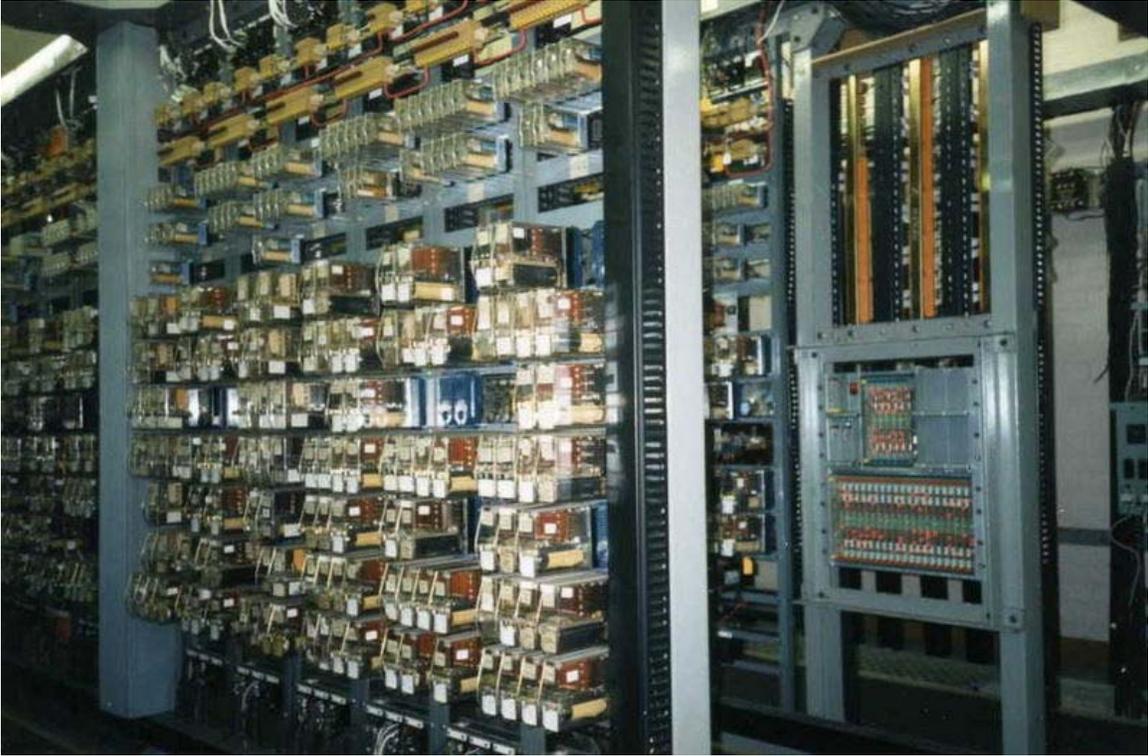
- Number and type of contacts – normally open, normally closed, (double-throw)
- Contact sequence – "Make before Break" or "Break before Make". For example, the old style telephone exchanges required Make-before-break so that the connection didn't get dropped while dialing the number.
- Rating of contacts – small relays switch a few amperes, large contactors are rated for up to 3000 amperes, alternating or direct current
- Voltage rating of contacts – typical control relays rated 300 VAC or 600 VAC, automotive types to 50 VDC, special high-voltage relays to about 15 000 V
- Coil voltage – machine-tool relays usually 24 VAC, 120 or 250 VAC, relays for switchgear may have 125 V or 250 VDC coils, "sensitive" relays operate on a few milliamperes

- Coil current
- Package/enclosure – open, touch-safe, double-voltage for isolation between circuits, explosion proof, outdoor, oil and splash resistant, washable for printed circuit board assembly
- Assembly – Some relays feature a sticker that keeps the enclosure sealed to allow PCB post soldering cleaning, which is removed once assembly is complete.
- Mounting – sockets, plug board, rail mount, panel mount, through-panel mount, enclosure for mounting on walls or equipment
- Switching time – where high speed is required
- "Dry" contacts – when switching very low level signals, special contact materials may be needed such as gold-plated contacts
- Contact protection – suppress arcing in very inductive circuits
- Coil protection – suppress the surge voltage produced when switching the coil current
- Isolation between coil circuit and contacts
- Aerospace or radiation-resistant testing, special quality assurance
- Expected mechanical loads due to acceleration – some relays used in aerospace applications are designed to function in shock loads of 50 g or more
- Accessories such as timers, auxiliary contacts, pilot lamps, test buttons
- Regulatory approvals
- Stray magnetic linkage between coils of adjacent relays on a printed circuit board.

Protective relays

For protection of electrical apparatus and transmission lines, electromechanical relays with accurate operating characteristics were used to detect overload, short-circuits, and other faults. While many such relays remain in use, digital devices now provide equivalent protective functions.

Railway signalling



Part of a relay interlocking using UK Q-style miniature plug-in relays.



UK Q-style signalling relay and base.

Railway signalling relays are very big and cumbersome compared to the mostly small voltages (less than 120 V) and currents (perhaps 100 mA) that they switch. Contacts are widely spaced to prevent dangerous flashovers and short circuits over a lifetime that may exceed fifty years. BR930 series plug-in relays are widely used on railways following British practice. These are 120 mm high, 180 mm deep and 56 mm wide and weigh about 1400 g, and can have up to 16 separate contacts, say 12 make and 4 break contacts.

Since rail signal circuits must be highly reliable, special techniques are used to detect and prevent failures in the relay system. To protect against false feeds, double switching relay contacts are often used on both the positive and negative side of a circuit, so that two false feeds are needed to cause a false signal. Not all relay circuits can be proved so there is reliance on construction features such as carbon to silver contacts to resist lightning induced contact welding and to provide AC immunity.

Opto-isolators are also used in some instances with railway signalling, especially where only a single contact is to be switched.

Chapter-11

Banyan Switch and DIP Switch

Banyan switch

In electronics, a **banyan switch** is a complex crossover switch used in electrical or optical switches.

It is named for its resemblance to the roots of the banyan tree which cross over in complex patterns. Logical banyan switches are used in logic or signal pathways to crossover switching of signals onto new pathways.

They can be mechanical Microelectromechanical systems, electrical or optical NLO. Their complexity depends on the topology of the individual switches in a switch matrix (how wide it is by how many 'plies' or layers of switches it takes), to implement a desired crossover logic.

Design

Typical crossover matrices follow this formula: an $N \times N$ banyan switch uses $(N/2) \log_2 N$ elements. Other formulas are used for differing number of crossover layers, and scaling is possible, but becomes very large and complex with large $N \times N$ arrays. CAD and AI can be used to take the drudgery out of creating these designs. A banyan network is implemented by interconnecting 2×2 switching networks in multiple and recursive stages.

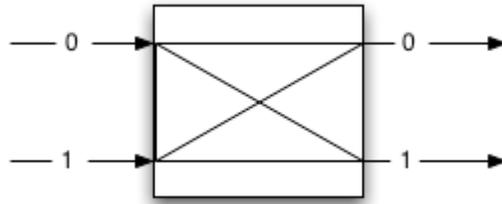
The switches are measured by how many stages, and how many up/down sorters and crosspoints they have. Switches often have buffers built-in for faster switching.

A typical switch may have:

1. A 2×2 and 4×4 down sorter
2. Followed by an 8×8 up sorter
3. Followed by a 2×2 crosspoint banyan switch network

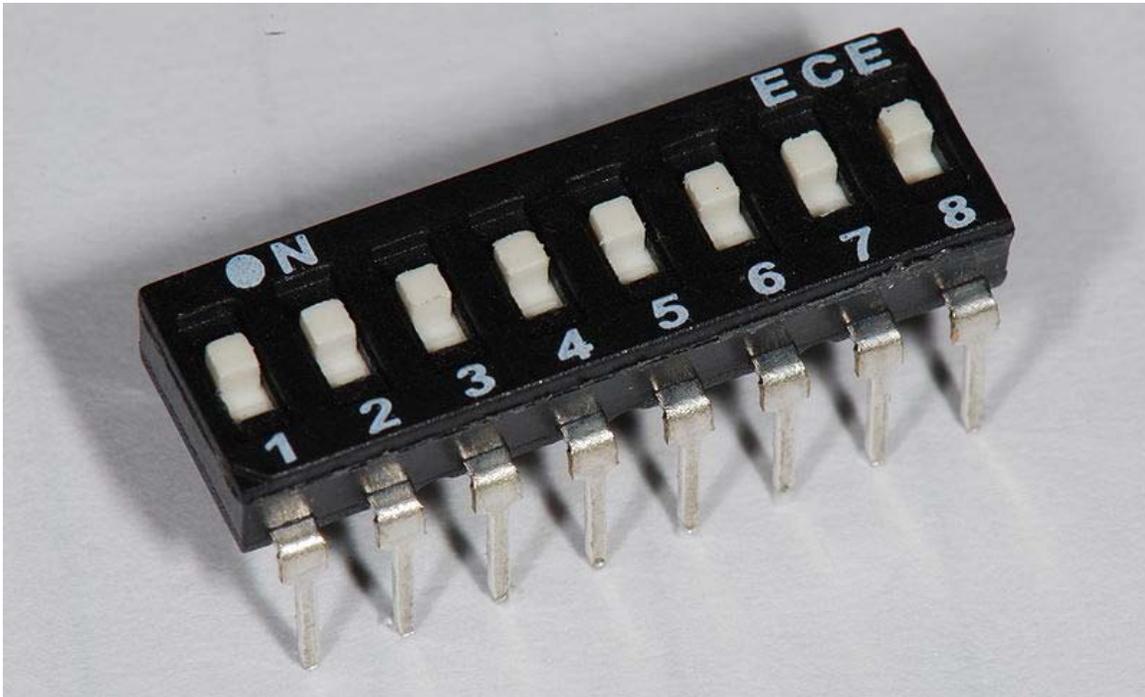
This results in 3 level sorting for a 3 stage banyan network switch.

A simple example

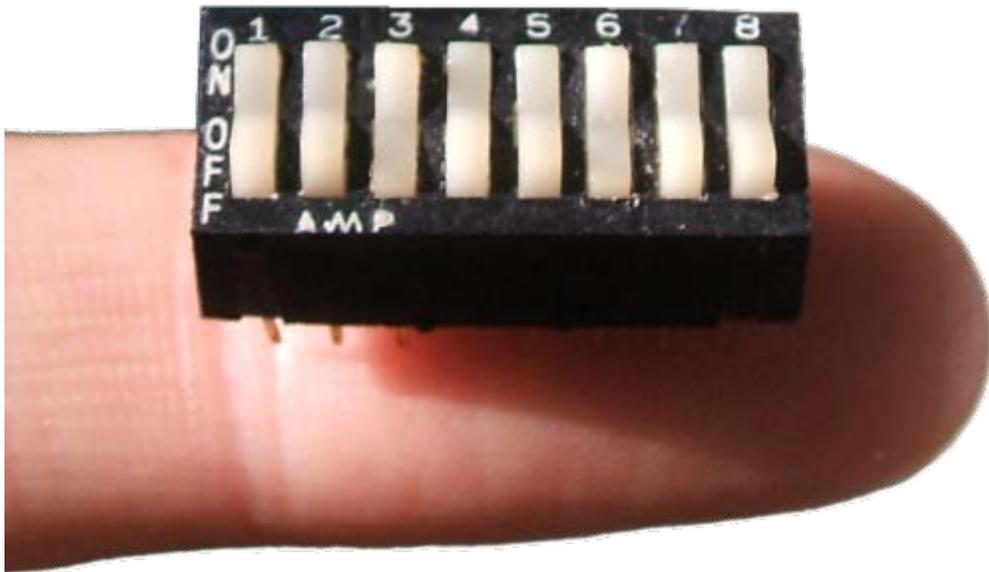


Consider a 2×2 banyan switch, which requires $(2/2) \log_2 2 = 1$ switching element. This switch takes two inputs, numbered 0 and 1, and two outputs, numbered 0 and 1. Every packet that comes in has a header that contains one bit indicating what its destination is (either 0 or 1). If the switch reads the bit and it has value 0, it sends the packet to its higher output (which is 0 in this case), and to its lower output if the routing bit is one. By connecting these switching elements in series and parallel it is possible therefore, to route packets in more complicated ways depending on the desired routes to establish.

DIP switch



Slide style dip switch



Rocker style dip switch

A **DIP switches** are manual electric switches that are packaged in a group in a standard dual in-line package (DIP) (the whole package unit may also be referred to as a DIP switch in the singular). This type of switch is designed to be used on a printed circuit board along with other electronic components and is commonly used to customize the behavior of an electronic device for specific situations.

DIP switches are an alternative to jumper blocks. Their main advantages are that they are quicker to change and there are no parts to lose.

DIP switch types

There are many different kinds of DIP switches. Some of the most common are the rotary, slide, and rocker types.

Rotary DIP switches contain multiple electrical contacts, one of which is selected by rotating the switch to align it with a number printed on the package. These may be large like thumbwheels, or so small that a screwdriver must be used to change them (although there are also small potentiometers of this type).

The slide and rocker types, which are very common, are arrays of simple SPST (single-pole, single-throw) contacts, which can be either on or off. This allows each switch to select a one-bit binary value. The values of all switches in the DIP package can also be interpreted as one number. For example, seven switches offer 128 combinations, allowing

them to select a standard ASCII character. Eight switches offer 256 combinations, which is equivalent to one byte.

The DIP switch package also has socket pins or mounting leads to provide an electrical path from the switch contacts to the circuit board. Although circuits can use the electrical contacts directly, it is more common to convert them into high and low signals. In this case the circuit board also needs interface circuitry for the DIP switch, consisting of a series of pull-up or pull-down resistors, a buffer, decode logic, and other components. Typically the device's firmware reads the DIP switches when the device is powered on.

Applications

DIP switches were extensively used in ISA PC cards to select IRQs and memory addresses. They were also often used on arcade games in the 1980s and early 1990s to store settings before the advent of cheaper, battery-backed RAM, and were very commonly used to set security codes on garage door openers as well as on some early cordless phones. This design, which used up to 12 switches in a group, was used to avoid RF interference from other nearby door opener remotes or other devices. Current garage door openers use rolling code systems for better security.

These type of switches were used on early video cards for early computers to facilitate compatibility with other video standards. For example, CGA cards allowed for MDA compatibility.

Recently (since the late 1990s), DIP switches have become less common in consumer electronics. Reasons include the trend toward smaller products, the demand for easier configuration through software menus, and the falling price of non-volatile memory. However, DIP switches are still widely used in industrial equipment because they are inexpensive and easy to incorporate into circuit designs, and because they allow settings to be checked at a glance without powering the system on.

DIP switches are still used in some remote controls to prevent interference; for example, to control a ceiling fan (and its light fixture) that was retrofitted to a single-circuit junction box. The remote not only allows for convenience (such as not having to fully awaken to get out of bed if installed in a bedroom), but also to control the fan motor speed and light dimmer, which cannot be installed at the wall switch without separate circuits. The DIP switches set a different radio frequency for each transmitter/receiver pair, so that multiple units can be installed in different rooms of the same house, or different units of the same apartment building, without unintentionally controlling each other.

Other types of remote controls use a fixed frequency in each unit, with a set of different frequencies used. For example, a control for table lamps or Christmas lights might be shipped from the vendor to the store in cases of six units, containing one unit each of frequencies A, B, C, D, E, and F, or two each of A, B, and C. Still others have DIP

switches that choose between A/B/C on half of the units, and D/E/F on the other half of the units made, for example.

Rotary switches are also used in X10 home automation to select house and unit numbers. Each of the two has 16 positions, encoding four bits to create an eight-bit (one-byte) address for each unit (up to 2^8 or 256). Rotary switches are also used in some radio transmitters (particularly VHF and FM broadcast) to select the DC bias used to set the voltage-controlled oscillator, which determines the center frequency of the carrier wave output.

Chapter-12

Crossbar Switch

In electronics, a **crossbar switch** (also known as **cross-point switch**, **crosspoint switch**, or **matrix switch**) is a switch connecting multiple inputs to multiple outputs in a matrix manner. Originally the term was used literally, for a matrix switch controlled by a grid of crossing metal bars, and later was broadened to matrix switches in general. It is one of the principal switch architectures, together with a memory switch and a crossover switch.

General properties

A crossbar switch is an assembly of individual switches between multiple inputs and multiple outputs. The switches are arranged in a matrix. If the crossbar switch has M inputs and N outputs, then a crossbar has a matrix with $M \times N$ cross-points or places where the "bars" cross. At each crosspoint is a switch; when closed, it connects one of M inputs to one of N outputs. A given crossbar is a single layer, non-blocking switch. Collections of crossbars can be used to implement multiple layer and/or blocking switches. A crossbar switching system is also called a co-ordinate switching system.

Applications

Crossbar switches are most famously used in information processing applications such as telephony and packet switching, but they are also used in applications such as mechanical sorting machines with inputs.

The matrix layout of a crossbar switch is also used in some semiconductor memory devices. Here the "bars" are extremely thin metal "wires", and the "switches" are fusible links. The fuses are blown or opened using high voltage and read using low voltage. Such devices are called programmable read-only memory. At the 2008 NSTI Nanotechnology Conference a paper was presented which discussed a nanoscale crossbar implementation of an adding circuit used as an alternative to logic gates for computation.

Furthermore, matrix arrays are fundamental to modern flat-panel displays. Thin-film-transistor LCDs have a transistor at each crosspoint, so they could be considered to include a crossbar switch as part of their structure.

For video switching in home and professional theater applications, a crossbar switch (or a matrix switch, as it is more commonly called in this application) is used to make the output of multiple video appliances available simultaneously to every monitor or every room throughout a building. In a typical installation, all the video sources are located on an equipment rack, and are connected as inputs to the matrix switch.

Where central control of the matrix is practical, a typical rack-mount matrix switch offers front-panel buttons to allow manual connection of inputs to outputs. An example of such a usage might be a sports bar, where numerous programs are displayed simultaneously. In order to accomplish this, a sports bar would ordinarily need to purchase a separate cable or satellite subscription for each display for which independent control is desired. The matrix switch enables the signals to be re-routed on a whim, thus allowing the establishment to purchase only those subscriptions needed to cover the total number of *unique* programs viewed anywhere in the building.

Such switches are used in high-end home theater applications. Video sources typically shared include set-top cable/satellite receivers or DVD changers; the same concept applies to audio as well. The outputs are wired to televisions in individual rooms. The matrix switch is controlled via an Ethernet or RS-232 serial connection by a whole-house automation controller, such as those made by AMX, Crestron, or Control4 - which provides the user interface that enables the user in each room to select which appliance to watch. The actual user interface varies by system brand, and might include a combination of on-screen menus, touch-screens, and handheld remote controls. The system is necessary to enable the user to select the program they wish to watch from the same room they will watch it from, otherwise it would be necessary (and arguably absurd) for them to walk to the equipment rack.

The special crossbar switches used in distributing satellite TV signals are called Multiswitches.

Implementations

Historically, a crossbar switch consisted of metal bars associated with each input and output, together with some means of controlling movable contacts at each cross-point. In the later part of the 20th Century these literal crossbar switches declined and the term came to be used figuratively for rectangular array switches in general. Modern "crossbar switches" are usually implemented with semiconductor technology. An important emerging class of optical crossbars is being implemented with MEMS technology.

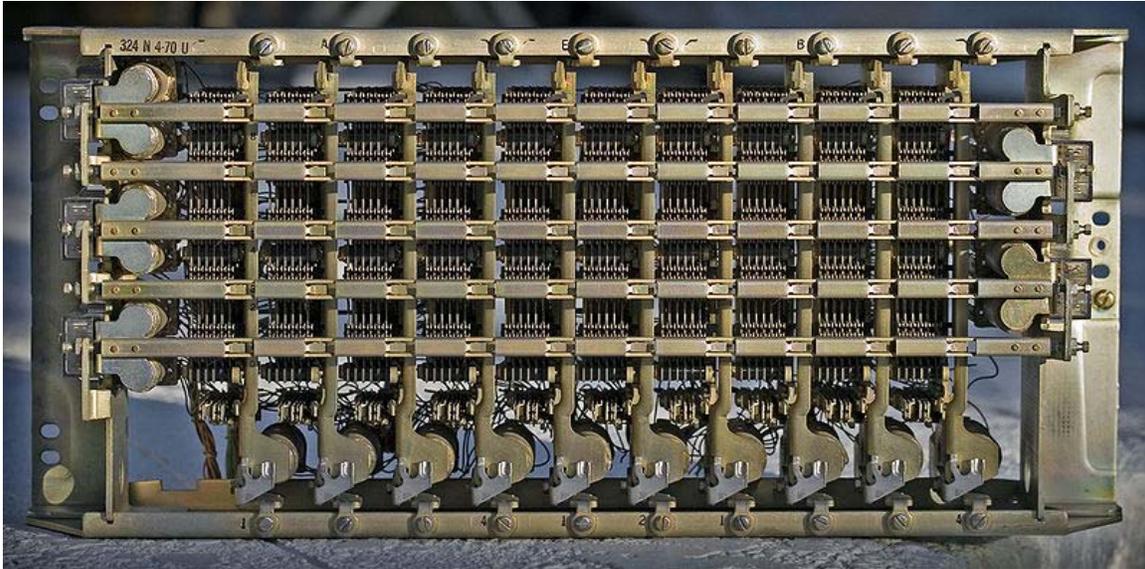
Mechanical

A type of middle 19th Century telegraph exchange consisted of a grid of vertical and horizontal brass bars with a hole at each intersection. The operator inserted a brass pin to connect one telegraph line to another.

Electromechanical/telephony

A telephony crossbar switch is an electromechanical device for switching telephone calls. The first design of what is now called a crossbar switch was Western Electric's "coordinate selector" of 1915. It was little used in America, but the LM Ericsson company used an improved version for rural exchanges in Sweden. To save money on control systems, this system was organized on the stepping switch or selector principle rather than the link principle. The system design used in AT&T's 1XB crossbar exchanges, which entered revenue service from 1938, was developed by Bell Telephone Labs, based on the rediscovered link principle. Delayed by the Second World War, several millions of urban 1XB lines were installed from the 1950s in the United States. Crossbar switching quickly spread to the rest of the world, replacing most earlier designs like the Strowger and Panel systems in larger installations in the U.S. Graduating from entirely electromechanical control on introduction, they were gradually elaborated to have full electronic control and a variety of calling features including short-code and speed-dialing. In the UK the Plessey Company produced a range of crossbar exchanges, but their widespread rollout by the British Post Office began later than in other countries, and then was inhibited by the parallel development of TXE reed relay and electronic exchange systems, so they never achieved a large number of customer connections although they did find some success as tandem switch exchanges.

Crossbar switches use switching matrices made from a two-dimensional array of contacts arranged in an x-y format. These switching matrices are operated by a series of horizontal bars arranged over the contacts. Each such "select" bar can be rocked up or down by electromagnets to provide access to two levels of the matrix. A second set of vertical "hold" bars is set at right angles to the first (hence the name, "crossbar") and also operated by electromagnets. The select bars carry spring-loaded wire fingers that enable the hold bars to operate the contacts beneath the bars. When the select and then the hold electromagnets operate in sequence to move the bars, they trap one of the spring fingers to close the contacts beneath the point where two bars cross. This then makes the connection through the switch as part of setting up a calling path through the exchange. Once connected, the select magnet is then released so it can use its other fingers for other connections, while the hold magnet remains energized for the duration of the call to maintain the connection. The crossbar switching interface was referred to as the TXK or TXC switch (*Telephone eXchange Crossbar*) - in the UK.

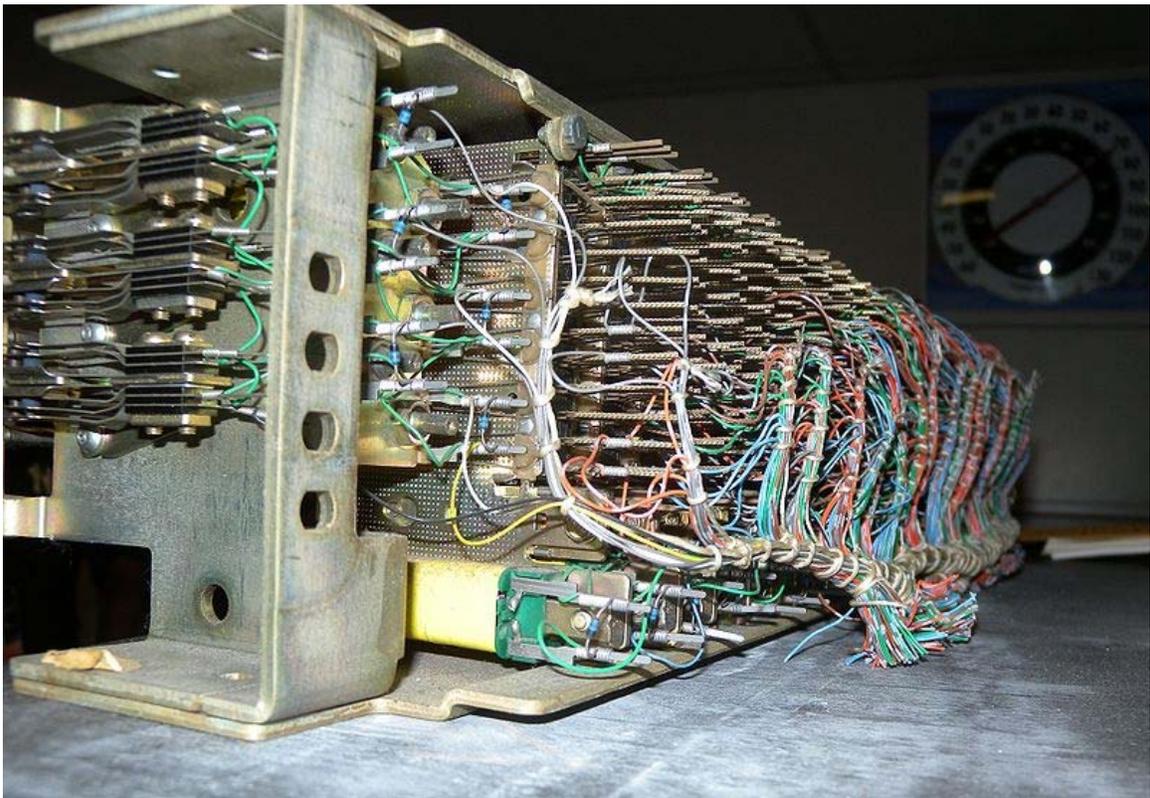


Western Electric 100 Point six-wire Type B crossbar switch

The Bell System *Type B* crossbar switch of the 1960s was made in the largest quantity. The majority were 200 point switches, with twenty verticals and ten levels of three wires, but this example is a 100 point six wire switch. Each select bar carries ten fingers so any of the ten circuits assigned to the ten verticals can connect to either of two levels. Five select bars, each able to rotate up or down, mean a choice of ten links to the next stage of switching. Each crosspoint in this particular model connected six wires. Note the *Vertical Off-Normal* contacts next to the hold magnets, lined up along the bottom of the switch. They perform logic and memory functions, and the hold bar keeps them in the active position as long as the connection is up. The *Horizontal Off Normals* on the sides of the switch are activated by the horizontal bars when the "butterfly magnets" rotate them. This only happens while the connection is being set up, since the butterflies are only energized then.



Late-model Western Electric crossbar switch



Back of Type C

The majority of Bell System switches were made to connect three wires including the tip and ring of a balanced pair circuit and a sleeve lead for control. Many connected six wires, either for two distinct circuits or for a four wire circuit or other complex connection. The Bell System *Type C* miniature crossbar of the 1970s was similar, but the fingers projected forward from the back and the select bars held paddles to move them. The majority of type C had twelve levels; these were the less common ten level ones. The Northern Electric *Minibar* used in SP1 switch was similar but even smaller. The ITT Pentaconta Multiswitch of the same era had usually 22 verticals, 26 levels, and six to twelve wires. Ericsson crossbar switches sometimes had only five verticals.

Electromechanical/instrumentation

For instrumentation use, James Cunningham, Son and Company made high-speed, very-long-life crossbar switches with physically-small mechanical parts which permitted faster operation than telephone-type crossbar switches. Many of their switches had the mechanical Boolean AND function of telephony crossbar switches, but other models had individual relays (one coil per crosspoint) in matrix arrays, connecting the relay contacts to [x] and [y] buses. These latter types were equivalent to separate relays; there was no logical AND function built in. Cunningham crossbar switches had precious-metal contacts capable of handling millivolt signals.

Telephone exchange

Early crossbar exchanges were divided into an originating side and a terminating side, while the later and prominent Canadian and US SP1 switch and 5XB switch were not. When a user picked up the telephone handset, the resulting line loop operating the user's line relay caused the exchange to connect the user's telephone to an originating sender, which returned the user a dial tone. The sender then recorded the dialed digits and passed them to the originating marker, which selected an outgoing trunk and operated the various crossbar switch stages to connect the calling user to it. The originating marker then passed the trunk call completion requirements (type of pulsing, resistance of the trunk, etc) and the called party's details to the sender and released. The sender then relayed this information to a terminating sender (which could be on either the same or a different exchange). This sender then used a terminating marker to connect the calling user, via the selected incoming trunk, to the called user, and caused the controlling relay set to pass intermittent ring voltage of about 90 VAC at 20 Hz to ring the called user's phone bell, and return ringing tone to the caller.

The crossbar switch itself was simple: exchange design moved all the logical decision-making to the common control elements, which as relay sets were themselves very reliable. The design criterion was to have two hours of "downtime" for service every forty years, which was a huge improvement on earlier electromechanical systems. The exchange design concept lent itself to incremental upgrades, as the control elements could be replaced separately from the call switching elements. The minimum size of a crossbar exchange was comparatively large, but in city areas with a large installed line capacity the whole exchange occupied less space than other exchange technologies of

equivalent capacity. For this reason they were also typically the first switches to be replaced with digital systems, which were even smaller and more reliable.

Two principles of using crossbar switches were used. One early method was based on the selector principle, and used the switches as functional replacement for Strowger or stepping switches. Control was distributed to the switches themselves. Call establishment progressed through the exchange stage by stage, as successive digits were dialed. With the selector principle, each switch could only handle its portion of one call at a time. Each moving contact of the array was multiplied to corresponding crosspoints on other switches to a selector in the next bank of switches. Thus an exchange with a hundred 10x10 switches in five stages could only have twenty conversations in progress. Distributed control meant there was no common point of failure, but also meant that the setup stage lasted for the ten seconds or so the caller took to dial the required number. In control occupancy terms this comparatively long interval degrades the traffic capacity of a switch.



"Banjo" wiring of a 100 point six wire Type B Bell System switch

Starting with the 1XB switch, the later and more common method was based on the link principle, and used the switches as crosspoints. Each moving contact was multiplied to the other contacts on the same level by simpler "banjo" wires, to a link on one of the inputs of a switch in the next stage. The switch could handle its portion of as many calls as it had levels or verticals. Thus an exchange with forty 10x10 switches in four stages could have a hundred conversations in progress. The link principle was more efficient, but required a more complex control system to find idle links through the switching fabric.

This meant common control, as described above: all the digits were recorded, then passed to the common control equipment - the marker - to establish the call at all the separate switch stages simultaneously. A marker-controlled crossbar system had in the marker a highly vulnerable central control; this was invariably protected by having duplicate markers. The great advantage was that the control occupancy on the switches was of the order of one second or less, representing the operate and release lags of the X-then-Y armatures of the switches. The only downside of common control was the need to provide digit recorders enough to deal with the greatest forecast originating traffic level on the exchange.

The Plessey TXK1 or 5005 design used an intermediate form, in which a clear path was marked through the switching fabric by distributed logic, and then closed through all at once.

In some countries, no crossbar exchanges remain in revenue service. However, crossbar exchanges remain in use in countries like Russia, where some massive city telephone networks have not yet been fully upgraded to digital technology. Preserved installations may be seen in museums like The Museum of Communications in Seattle, Washington, and the Science Museum in London.

Changing nomenclature can confuse: in current American terminology a "switch" now frequently refers to a system which is also called a "telephone exchange" (the usual term in English)--that is, a large collection of selectors of some sort within a building. For most of the twentieth century a "Strowger switch" or a "crossbar switch" referred to an individual piece of mechanical equipment making up part of an exchange. Hence the pictures above show a "crossbar switch" using the earlier meaning.

Semiconductor

Semiconductor implementations of crossbar switches typically consist of a set of input amplifiers or retimers connected to a series of metalizations or "bars" within a semiconductor device. A similar set of metalizations or "bars" are connected to output amplifiers or retimers. At each cross-point where the "bars" cross, a pass transistor is implemented which connects the bars. When the pass transistor is enabled, the input is connected to the output.

As computer technologies have improved, crossbar switches have found uses in systems such as the multistage interconnection networks that connect the various processing units in a Uniform Memory Access parallel processor to the array of memory elements.

Arbitration

A standard problem in using crossbar switches is that of setting the cross-points. In the classic telephony application of cross-bars, the crosspoints are closed and open as the telephone calls come and go. In Asynchronous Transfer Mode or packet switching applications, the crosspoints must be made and broken at each decision interval. In high-

speed switches, the settings of all of the cross-points must be determined and then set millions or billions of times per second. One approach for making these decisions quickly is through the use of a wavefront arbiter.

Chapter-13

Light Switch



An Australian "down" light switch in the "on" position.

A **light switch** is a switch, most commonly used to operate electric lights, permanently connected equipment, or electrical outlets. In torches (flashlight) the switch is often near

the bulb, but may be in the tail, or even the entire head itself may constitute the switch (rotated to turn the light on and off).



Two light switches and their wiring.

Wall-mounted switches

Switches for lighting may be in hand-held devices, moving vehicles and buildings. Residential and commercial buildings usually have wall-mounted light switches to control lighting within a room. Mounting height, visibility, and other design factors vary from country to country. Switches are often recessed within a finished wall. Surface mounting is also fairly common though is seen more in commercial industrial and outbuilding settings than in houses. Light switches boxes have plastic, ceramic or metal

covers to prevent accidental contact with live terminals of the switch. Wall plates are available in different styles and colours to blend in with the style of a room.

History and culture



Two light switches in one box. The switch on the right is a dimmer switch. The switch box is covered by a decorative plate.

The first light-switch employing **quick-break technology** was invented by John Henry Holmes in 1884 in the Shieldfield district of Newcastle-Upon-Tyne. Holmes was a prolific inventor of other electrical devices including the "Castle" dynamo and early electrical systems in trains.

The **toggle light switch** was invented in 1916 by William J. Newton and Morris Goldberg.

As a component of a building wiring system, installation of light switches will be regulated by some authority concerned with safety. The dimensions, mechanical designs, and even the general appearance of light switches changes very slowly with time. They frequently remain in service for many decades, often being changed only when a portion of a house is rewired. It is not extremely unusual to see century-old light switches still in functional use. Manufacturers introduce various new forms and styles, but for the most

part decoration and fashion concerns are limited to the faceplates. Even the "modern" dimmer switch with knob is at least four decades old, and even in the newest construction the familiar toggle and rocker switch appearances predominate. The shape and size of the boxes and faceplates as well as what is integrated (for example in the UK it is normal to have the switch built into the plate) varies a lot by country.

Up or down

The direction which represents "on" also varies by country. In North America, it is usual for the "on" position of a toggle switch to be "up", whereas in many other countries such as the UK, Ireland, Australia, and in New Zealand it is "down." In multiway switching, the correspondence between a single switch's state and whether lights are on or off depends on other switches in the circuit. In countries prone to earthquakes, such as Japan, most switches are positioned sideways to prevent the switch from inadvertently being turned on or off by falling objects.

Design



A rocker switch, with a cover screwed in to prevent electrical shocks caused by water coming into contact with the wires.

The switches may be single or multiple, designed for indoor or outdoor use. Optional extras may include dimmer-controls, environmental protection, weather & security protection.

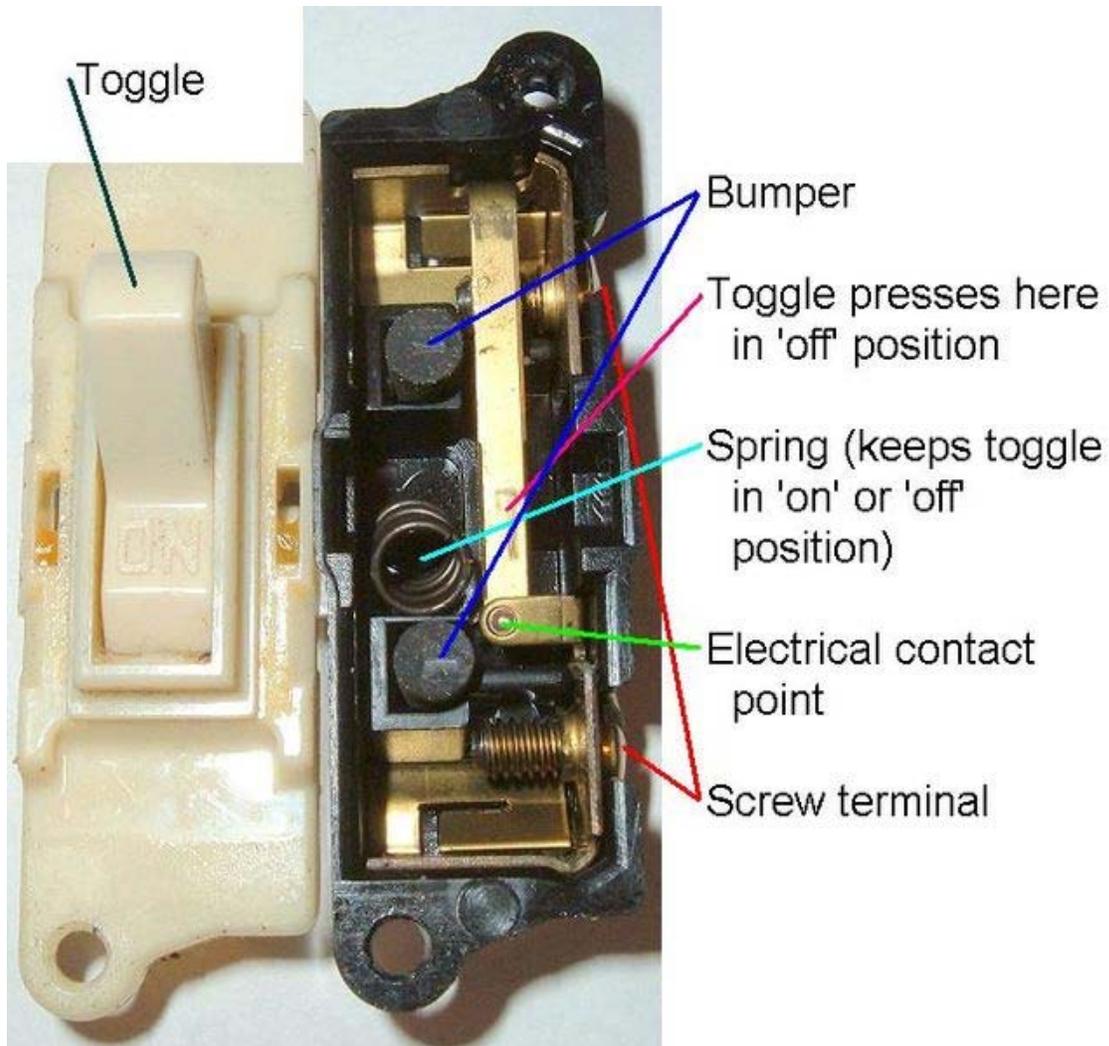
In the case of light switches, the circuit to be switched is within 10% of 230 volts at 5A 6A or 10A for all European and most of South American, African and Asian countries, whereas Japan and North America use a supply between 100 and 127 volts with maximum circuit currents of up to 15 or 20 amperes so the overall power per circuit is

similar. In the UK putting normal 13A BS1363 sockets on a lighting circuit is frowned upon (though not explicitly prohibited) but 2A or 5A BS546 outlets are often put on lighting circuits to allow control of free-standing lamps from the room's light switches. In the U.S., this is very common in mobile homes. It is common in American site-built housing for living rooms and bedrooms to have a switched receptacle for a floor or table lamp.

Internal operation



Internal operation of a toggle switch (explanation)



Internal operation of a toggle switch, explained

A switch is most vulnerable when the contacts are opening or closing. As the switch is closed, the resistance of the switch changes from nearly infinite to nearly zero. At infinite resistance, no current flows and no power is dissipated. At zero resistance, there is no voltage drop and no power is dissipated. When the switch changes state however, there is a brief instant of partial contact when resistance is neither zero nor infinite and power is dissipated. During that transition the contacts heat up. If the heating is excessive, the contacts can be damaged or even weld themselves closed.

Thus the switch is designed to make the transition between effectively infinite resistance and effective zero resistance as swiftly as possible. This is achieved by the initial operation of the switch lever mechanism storing potential energy, usually as stress in a spring. When sufficient energy is stored, the mechanism in the switch "breaks over" driving the contacts through the transition from open to close, or close to open, without further input by the switch operator. This **quick-break** action of the switch is the secret

to a long life for the switch contacts without them burning out, as disclosed in Holmes' 1884 patent.

In addition, during the transition when the contact is broken there is an additional issue that if an inductive load is being switched, the stored energy in the inductor is dissipated as an arc within the switch, prolonging the transition and worsening the heating effect on the contacts. Thus switches are commonly rated by the current they are designed to break, as this is the most stringent constraint.

The arc that results when the switch operates corrodes the switch contacts, in time leading to erosion of the contact surface and fouling of the contact area by corrosion byproducts. A switch therefore has a finite life, again often being rated at a given number of cycles of disconnection at a specified current. Operation outside its design envelope will shorten the switch life very drastically.

To combat contact corrosion a switch is usually designed to have a wipe action such that the contact corrosion is cleaned off the area of the contact that forms the low resistance path when the switch is closed. It's also designed so that the initial point of contact, and thus the majority of the contact corrosion, occurs at a sacrificial part of the contact, rather than the face that is in contact when the switch is fully closed. Depending on the switch rating and price, the contact area of the switch is often a sophisticated construction of brass contact, silver contact button, and plated finish to minimize the amount of contact corrosion and thus extend the life of the switch.

Many higher current switch designs rely on the separation arc to assist in dispersing contact corrosion, and that a switch designed for high current/high voltage use may become unreliable if operated at very low currents and low voltages because the contact corrosion builds up excessively without an arc to disperse it.

When a pair of contacts are badly designed, the contacts themselves are visible, or the switch is overloaded in relation to its design then there are two kinds of "sparks" which may be seen. On closure, a few sparks like those from a flint-and-steel may appear as a tiny bit of metal is heated to incandescence, melted, and thrown off. On opening, a bluish arc may occur with a detectable "electrical" (ozone) smell; afterwards the contacts may be seen to be darkened and pitted. Damaged contacts have higher resistance, rendering them more vulnerable to further damage and causing a vicious circle in which the contacts soon fail completely.

To make a switch safe, durable, and reliable, it must be designed so that the contacts are held firmly together under positive force when the switch is closed. It should be designed so that regardless of how the person operating the switch manipulates it, the contacts always close or open quickly. Despite this, a switch should not be held between its two positions (on or off); this is especially true on older mechanisms.

The spring that stores the energy necessary for the snap action of the switch mechanism, in many small switch designs is made of a beryllium copper alloy, that is hardened to

form a spring as part of the fabrication of the contact. The same part often also forms the body of the contact itself, and is thus the current path. Abusing the switch mechanism to hold the contacts in a transition state, or severely overloading the switch, will heat and thus anneal the spring, reducing or eliminating the "snap action" of the switch, leading to slower transitions, more energy dissipated in the switch, and progressive failure.

Variations on design

Push button



A push button light switch.

Prior to the toggle switch a popular design was the push-button switch, composed of a depressed button oriented below or beside a raised button. Pushing the raised button opens or closes the contacts while popping out the previously depressed button so the process can be reversed. Push button switch reproductions are available on the market today for vintage or authentic styling.

Toggle



A toggle light switch.

The traditional light-switch mechanism is a toggle mechanism that provides "snap-action" through the use of an "overcenter" geometry. The design was patented in 1916 by William J. Newton and Morris Goldberg. The switch handle does not control the contacts directly, but through an intermediate arrangement of springs and levers. Turning the handle does not initially cause any motion of the contacts, which in fact continue to be positively held open by the force of the spring. Turning the handle gradually stretches the spring. When the mechanism passes over the center point, the spring energy is released and the spring, rather than the handle, drives the contacts rapidly and forcibly to the closed position with an audible "snapping" sound. The snap-action switch is a mechanical example of negative resistance.

This mechanism is safe, reliable, and durable, but produces a loud snap or click. (Many people have at some point in their lives made an attempt to reduce this noise by operating the handle slowly or gingerly. Of course this is to no avail, since the very purpose of the mechanism is to ensure that the electrical portion of the switch always operates rapidly and forcefully — and noisily — regardless of how the handle is manipulated).

As of 2004 in the United States, the toggle switch mechanism was almost entirely supplanted by "quiet switch" mechanisms. "Quiet switch" mechanisms still possess a form of snap action, but which is very weak as compared to its predecessor. They are therefore equipped with larger, high-quality contacts that are capable of switching domestic loads without damage, despite the less-positive action.

Illuminated switch



An illuminated switch in the off position

An illuminated light switch has an internal light source (either a neon lamp or an LED) which allows the user to locate the switch in the dark. Most European illuminated switches are two pole requiring the live and neutral wires to pass into the switch which

enables the neon to be powered directly from the mains via a resistor. The internal light source in a single pole illuminated switch derives its power when the switch is OFF from current passing through the external light bulb. Single pole illuminated switches work well with incandescent bulbs, non-electronic fluorescent light fixture and halogen lighting, but they can cause a few compact fluorescent lamps to behave erratically. The current through the neon lamp in the switch can slowly charge the internal input capacitor in these lamps, until they begin to operate and produce a brief discharge. This cycle may repeat indefinitely in some cases, resulting in brief repetitive flashing while the switch is in the "off" position.

Rocker



A rocker switch

An alternative design to the toggle switch is the rocker, commonly known as "decorator" in the United States. An example is the Leviton "Decora". This design sits flush to the wall, and is activated by "rocking" a paddle, rather than pushing a short protruding handle up and down.

In the UK, Ireland, Hong Kong, Singapore and India this type is near-universal, where the toggle design would be considered old-fashioned.

In Australia, a miniature rocker switch is near universally used, with a 1cm oval switch that slots into a backing plate. Clipsal make a large cover plate that clips over the assembly, and can be removed for painting, which is very common. The same switch is also used in sockets, and it is extremely rare to find any other type of switch in Australian homes, although the Australian Wiring Standard AS 3112 does not forbid other types. Some Australian home renovators import UK designed switches when they are aiming for a high quality finish, due to the lack of Australian designs.

Tamper resistant

Where lighting circuits must not be accidentally switched off (for example, school corridors), tamper-resistant or vandal resistant light switches may be installed. These require a key to operate and so discourage casual or accidental operation of the switch.

Voltage class

In North American commercial and industrial lighting installations, lighting installed on 480Y/277 V 3 phase circuits uses voltages higher than the rating of common 120 V switches. Switches for these circuits are physically larger, so that a low-voltage switch is unlikely to be accidentally interchanged with one rated for 277 V - the low voltage switch will not align with the mounting holes in the switch box.

Mercury switches



General Electric Brand mercury light switch circa 1960, 15 Amp 120V

Before the 1970s, mercury switches were popular. They cost more than other designs, but were totally silent in operation. The switch handle simply tipped a glass vial, causing a large drop of mercury to roll from one end to the other. As it rolled to one end, the drop of mercury bridged a pair of contacts to complete the circuit. Many of them also would glow faintly when they were "off" to aid people in finding them when the room was dark. The vial was hermetically sealed, but concerns about the release of toxic mercury when the switches were damaged or disposed of led to the abandonment of this design. In the U.S. there has never been any effort to recall or replace existing mercury switches, and millions of them remain in use.

Pull chain/pull cord

A light switch combined with a light socket is sometimes installed in basement or utility areas of homes. The switch is operated by a pull chain or cord. This type is particularly common in British bathrooms, on the basis that it prevents people with wet hands from making accidental electrical contact with the mains power supply. Until 2001 it was a legal requirement that all bathroom switches were of this type, and although this regulation has been relaxed, new installations in the UK still almost exclusively use this type of switch. A common way around this issue was to fit the light switch just outside the bathroom door.

Dimmer switch

A dimmer switch contains a solid-state circuit to allow changing the brightness by reducing the average voltage applied to the lamp.

Electronic switches

In principle, it is easy to design silent switches in which the mechanical contacts do not directly control the current, but simply signal a solid-state device such as a thyristor to complete the circuit. Many variations on this theme have been created and marketed. "Touch-plate" devices can be operated by touching or merely waving a hand near the switch. Touch switches have no moving parts and electronically switch the light circuit. Public buildings such as hospitals frequently save energy by using motion detector switches. As of 2006 these remain specialty items. Electronic switches provide flexibility in terms of different interfaces for their operations, such as touch plates, soft-touch controls, pressure / light sensor based control, interactive touch-screens (which are widely used in aircraft for lighting control) and others.

A wireless light switch provides remote control of lighting using a hand-held transmitter. Wired remote control of lighting switches is possible using, for example, X10 signaling over the power wires.

Multiway switching

Two or more light switches can be interconnected to allow control of lighting from, for example, two ends of a long hallway or landings at the upper and lower landings of a flight of stairs.

Chapter-14

Mercury Switch and Miniature Snap-Action Switch

Mercury switch



A Single-Pole, Single-Throw (SPST) mercury switch



Another mercury switch design

A **mercury switch** (also known as a **mercury tilt switch**) is a switch whose purpose is to allow or interrupt the flow of electric current in an electrical circuit in a manner that is dependent on the switch's physical position or alignment relative to the direction of the "pull" of earth's gravity, or other inertia.

Mercury switches consist of one or more sets of electrical contacts in a sealed glass envelope which contains a bead of mercury. The envelope may also contain air, an inert gas, or a vacuum. Gravity is constantly pulling the drop of mercury to the lowest point in the envelope. When the switch is tilted in the appropriate direction, the mercury touches a set of contacts, thus completing the electrical circuit through those contacts. Tilting the switch the opposite direction causes the mercury to move away from that set of contacts, thus breaking that circuit. The switch may contain multiple sets of contacts, closing different sets at different angles allowing, for example, Single-Pole, Double-Throw (SPDT) operation.

Advantages of the mercury switch over other types are that the contacts are enclosed, so oxidation of the contact points is unlikely; in hazardous locations, interrupting the circuit will not emit a spark that can ignite flammable gasses. Contacts stay clean, and even if an internal arc is produced, the contact surfaces are renewed on every operation, so the

contacts don't wear out. Even a small drop of mercury has a low resistance, so switches can carry useful amounts of current in a small size. The sensitivity of the drop to gravity provides a unique sensing function, and lends itself to simple, low-force mechanisms for manual or automatic operation. The switches are quiet as there are no contacts that abruptly snap together. The mass of the moving mercury drop can provide an "over center" effect to avoid chattering as the switch is tilted. Multiple contacts can be included in the envelope for two or more circuits.

Disadvantages when compared with other types include: Mercury switches have a relatively slow operating rate due to the inertia of the mercury drop, so they are not used when many operating cycles are required per second. Mercury switches are sensitive to gravity so may be unsuitable in portable or mobile devices that can change orientation or that vibrate. Mercury compounds are highly toxic and accumulate in any food chain, so mercury is not permitted in many new designs. Glass envelopes and wire electrodes may be fragile and require flexible leads to prevent damaging the envelope. The mercury drop forms a common electrode, so circuits are not reliably isolated from each other if a multipole switch is used.

Uses

Roll sensing

Tilt switches may be used for a rollover or tip over warning for construction equipment and lift vehicles operating in rugged off-highway terrain. There are several non-mercury types but few are implemented due to sensitivity to shock and vibration - causing false tripping. However devices resistant to this do exist.

Automotive uses

Mercury switches were used in automobiles for lighting controls (for example, trunk lid lights), ride control, and Antilock braking control systems. Scrapped automobiles can leak mercury to the environment if these switches are not properly removed. These uses have been discontinued in new American-built cars since 2003.

Fall alarms

Work performed in confined space (such as a welder inside a tank) has special labor safety requirements. Tilt switches are used to sound an alarm if a worker falls over.

Thermostats

Mercury switches were commonly used in bimetal thermostats. The weight of the movable mercury drop provided some hysteresis by moving the bimetal spring slightly beyond the point it would normally assume, thereby holding the thermostat off slightly longer before flipping to the on state and then holding the thermostat on slightly longer before flipping back to the off state. The mercury also provided a very positive on/off

switching action and could withstand millions of cycles without degradation of the contacts.

Vending

Mercury switches are still used in mechanical systems that are controlled electrically where the physical orientation of actuators or rotors is a factor. They are also commonly used in vending machines that have 'tilt alarms'. When the machine is rocked or tilted in an attempt to gain a product, the mercury switch activates, sounding an alarm.

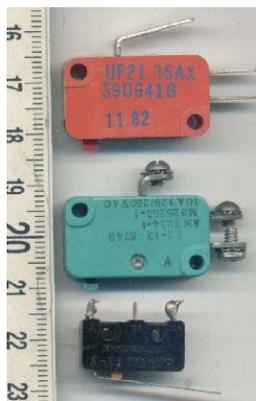
Bombs

A tilt switch can be used to trigger a bomb. Mercury tilt switches can be found in some bomb and landmine fuzes, typically in the form of anti-handling devices, for example, a variant of the VS-50 mine.

Toxicity

Since mercury is a poisonous heavy metal, devices containing mercury switches must be treated as hazardous waste for disposal. Because it is now RoHS restricted, it has been eliminated in most modern applications. A metal ball and contact wires can directly replace it, yet switch bounce reduction may be necessary. Low-precision thermostats simply use a bimetal strip and a switch contact; precision thermostats use a thermistor or silicon temperature sensor. Low-cost accelerometers replace the mercury tilt switch in precision applications.

Miniature snap-action switch



Comparison of some different switches.

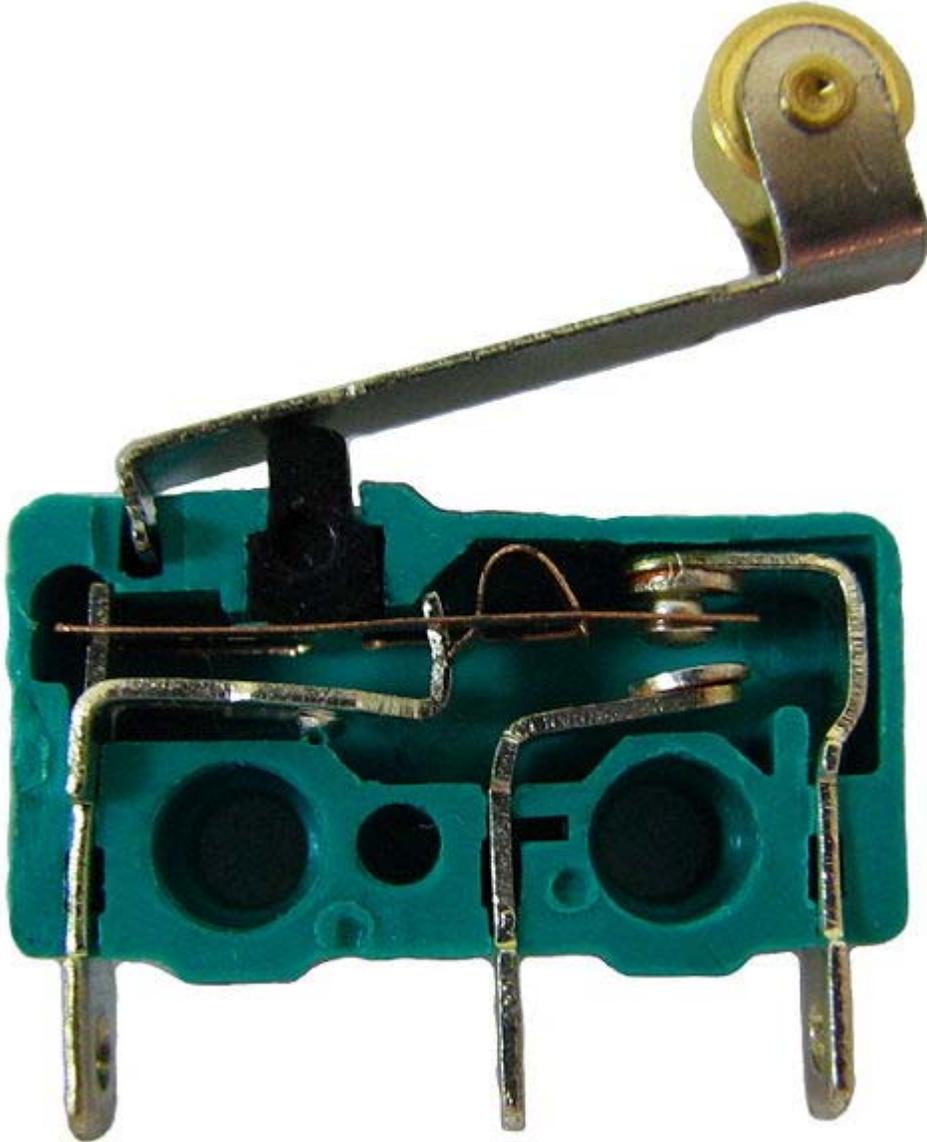
A **miniature snap-action switch**, also trademarked and frequently known as a **micro switch**, is an electric switch that is actuated by very little physical force, through the use of a tipping-point mechanism, sometimes called an "over-center" mechanism. Switching happens reliably at specific and repeatable positions of the actuator, which is not necessarily true of other mechanisms. They are very common due to their low cost and durability, greater than 1 million cycles and up to 10 million cycles for heavy duty models. This durability is a natural consequence of the design.

The defining feature of micro switches is that a relatively small movement at the actuator button produces a relatively large movement at the electrical contacts, which occurs at high speed (regardless of the speed of actuation). Most successful designs also exhibit hysteresis, meaning that a small reversal of the actuator is insufficient to reverse the contacts; there must be a significant movement in the opposite direction. Both of these characteristics help to achieve a clean and reliable interruption to the switched circuit.

History

The first micro switch was invented by Peter McGall in 1932 in Freeport, Illinois. McGall was an employee of the Burgess Battery Company at the time. In 1937 he started the company MICRO SWITCH. The company and the *Micro Switch* trademark has been owned by Honeywell Sensing and Control since 1950. The trademark has become a widely used description for snap-action switches. Companies other than Honeywell now manufacture miniature snap-action switches.

Construction and operation



The internals of a micro switch. Contacts, from left to right, are common, normally open, and normally closed.

Internally, a microswitch contains two springs. Both are conductive and carry the current through the switch.

A long flat spring is hinged at one end of the switch (the left, in the photograph) and has electrical contacts on the other. A small curved spring, preloaded (i.e. compressed during assembly) so it attempts to extend itself (at the top, just right of center in the photo), is connected between the flat spring near the contacts. A fulcrum is near the midpoint of the flat spring. An actuator nub presses on the flat spring near its hinge point.

Because the flat spring is anchored and strong in tension the curved spring cannot move it to the right. The curved spring presses, or pulls, the flat spring upward, that is away, from the anchor point. Owing to the geometry, the upward force is proportional to the displacement which decreases as the flat spring moves downward. (Actually, the force is proportional to the sine of the angle, which is approximately proportional to the angle for small angles.)

As the actuator depresses it flexes the flat spring while the curved spring keeps the electrical contacts touching. When the flat spring is flexed enough it will provide sufficient force to compress the curved spring and the contacts will begin to move.

As the flat spring moves downward the upward force of the curved spring reduces causing the motion to accelerate even in the absence of further motion of the actuator until the flat spring impacts the normally-open contact. Even though the flat spring unflexes as it moves downward, the switch is designed so the net effect is acceleration. This "over-center" action produces a very distinctive clicking sound and a very crisp feel.

In the actuated position the curved spring provides some upward force. If the actuator is released this will move the flat spring upward. As the flat spring moves, the force from the curved spring increases. This results in acceleration until the normally-closed contacts are hit. Just as in the downward direction, the switch is designed so that the curved spring is strong enough to move the contacts, even if the flat spring must flex, because the actuator does not move during the changeover.

Applications

Common applications of micro switches include the door interlock on a microwave oven, levelling and safety switches in elevators, vending machines, and to detect paper jams or other faults in photocopiers. Micro switches are commonly used in tamper switches on gate valves on fire sprinkler systems and other water pipe systems, where it is necessary to know if a valve has been opened or shut.

Micro switches are very widely used; among their applications are appliances, machinery, industrial controls, vehicles, and many other places for control of electrical circuits. They are usually rated to carry current in control circuits only, although some switches can be directly used to control small motors, solenoids, lamps, or other devices. Special low-force versions can sense coins in vending machines, or with a vane attached, air flow. Micro switches may be directly operated by a mechanism, or may be packaged as part of a pressure, flow, or temperature switch, operated by a sensing mechanism such as a Bourdon tube. In these latter applications, the repeatability of the actuator position when switching happens is essential for long-term accuracy. A motor driven cam (usually relatively slow-speed) and one or more micro switches form a timer mechanism. The snap-switch mechanism can be enclosed in a metal housing including actuating levers, plungers or rollers, forming a limit switch useful for control of machine tools or electrically-driven machinery.

Chapter-15

Stepping Switch

In electrical controls, a **stepping switch**, also known as a stepping relay, is an electromechanical device which allows an input connection to be connected to one of a number of possible output connections, under the control of a series of electrical pulses. It can step on one axis (called a **uniselector**), or on two axes (a **Strowger switch**). Stepping switches were invented by Almon Strowger in 1888. The major use for these devices was in early automatic telephone exchanges (commonly called *Strowger* or step-by-step exchanges or *steppers*) to route telephone calls. Later, they were often used in such equipment as industrial control systems.

Single-axis stepping switches (uniselectors)



An example of an historic Strowger-type selector assembly. This has a single (vertical) axis, and is driven by a gear instead of a typical electromagnet.

Stepping switches were widely used in telephony and industrial control systems (among related applications) when electromechanical technology was paramount.

A basic stepping switch is an electrically-operated rotary switch with a single (typically input) terminal, and multiple (typically output) terminals. Like other typical rotary switches, the single terminal connects to one of the multiple terminals by rotating a contact arm, sometimes called a wiper, to the desired position. Moving from one position to the next is called stepping, hence the name of the mechanism. Using traditional terminology, this is a single-pole, multi-position switch.

While some stepping switches have only one pole (layer of contacts), a typical switch has more; in the latter case, all wipers are aligned and move together. Hence, one input with multiple wires could be connected to one of multiple outputs, based on the receipt of a single set of pulses. In this configuration, the rotating contacts looked, in general, somewhat like the head support arms in a modern rigid ("hard") disk drive. Multipole switches were common; some had perhaps as many as a dozen poles, but those were less common.

Most switches have a bank of stationary contacts extending over half a cylinder, while some have only a third of a cylinder. The typical "half-cylinder" switch has two sets of wiper contacts opposite each other, while the "third of a cylinder" type has three sets, equally spaced. For any given level, both or all three wipers are connected, so it makes no difference which of the two (or three) is connecting.

An electromagnet advances (steps) the wipers to the next position when fed with a pulse of DC. The magnet's armature (spring-loaded) operates a pawl that advances a ratchet. When the pawl reaches its full stroke, it blocks the ratchet so it and the wipers will not overshoot. When power to the coil disconnects, the spring retracts the pawl. Another pawl pivoted on the frame ensures that the wipers do not move backward; contact friction keeps them in place.

In most applications, such as telephony, it is desirable to be able to return the wipers to a "home" position; this is at the beginning of rotation, at one end of the array of fixed contacts. Some switches have a cam attached to the wiper shaft. This cam operates a set of contacts when the wiper is at home position, which is at the beginning of the span of rotation. Other circuit designs used one level (pole) of the contacts to home the wipers, so the separate homing contacts weren't needed.

Typical stepping switches have contacts directly operated by the stepping magnet's armature; these contacts can serve to make the magnet cycle ("self-step") and advance the wipers as long as power is applied. The external control circuits remove power when the wipers reach the desired position; that could be the home position.

Most stepping switches rotate the wipers in only one direction, but some are bidirectional; the latter have a second magnet to rotate the wipers the other way. A third variety "winds" a spring as the wiper steps progressively, and a ratchet holds the wipers from returning to home position. When the circuit is no longer needed, another electromagnet releases the holding pawl; the spring then returns the wipers back to home.

Stepping switches were quite noisy in operation (especially when self-stepping), because their mechanisms accelerated and stopped quickly to minimize operating time. One could compare their sound to that of some snap-action mechanisms. Nevertheless, they were engineered for long life, given periodic maintenance; they were quite reliable.

So far, this description refers only to single-axis stepping switches, sometimes known as uniselectors.

Two axis stepping switch

Slightly more complicated was the *two axis stepping switch*, (also called *Strowger switch* or *two motion selector* in Britain). Typically, a single compact group of wipers could connect to one of 100 different fixed contacts. When the switch was idle, the wipers were disengaged from the fixed contacts. The wipers moved up and down on a vertical shaft, and rotated into the contact bank to make a connection. Gravity returned the wipers to their home position at the bottom.

This type had two stepping coils with pawls and ratchets, one to raise the wipers to the desired banks of contacts, and one to rotate the wipers into the banks. These were commonly used in telephone switching with ten banks of ten contacts. The coils were typically driven by the electrical pulses derived from a rotary telephone dial. On a two-motion selector, as a digit was dialed, the wipers would step up the banks, then automatically rotate (self-step) into the selected bank until they found an "unused" outlet to the next switch stage. The last two digits dialed would operate the connector switch (*final selector* in Britain). The second to last digit would cause the wipers to move up and the last digit would cause them to rotate into the bank to the called customer's line outlet. If the line was idle then ringing voltage would be applied to the called line and ringing tone was sent to the calling line.

Another variant of the two-axis switch was the **Stromberg-Carlson X-Y Switch** which was quite common in telephone exchanges in the western USA. It was a flat mechanism, and the moving contacts moved both sidewise, as well as to and fro. It was quite reliable, and could be maintained by people with minimal training.

Applications of stepper switches

As well as the decoding of pulses from telephones, stepping switches could be used for a variety of purposes, depending on how they were wired. By connecting several in series with the highest output of one going to the stepping contact of the next, a counter could be constructed. Or by feeding the stepping contact with an endless pulse train via a relay, and controlling the relay from the switch's own output, it can be made to automatically hunt for the first unpowered line (or powered, depending on whether the relay is normally open or normally closed). They could also be used as a demultiplexer, so that two input lines could control a number of output devices. One input line steps the switch until the correct device is selected, and the other than powers that device. Many other applications are possible.

Such switches were used in a series of Japanese cypher machines during World War 2: CORAL, JADE, PURPLE (the names were American). Some of the equipment used to break the Enigma machine code also used many such switches, which some observers called the "Machine Gun" for the loud noise.

Chapter-16

Transfer Switch and Vandal Resistant Switch

Transfer switch

A **transfer switch** is an electrical switch that reconnects electric power source from its primary source to a standby source. Switches may be manually or automatically operated. An Automatic Transfer Switch (ATS) is often installed where a backup generator is located, so that the generator may provide temporary electrical power if the utility source fails.

Operation of a transfer switch

An ATS not only safely switches-in the backup generator as a temporary source of electric power; it also commands the backup generator to start, based on certain conditions it continuously monitors on the primary feed. The transfer switch isolates the backup generator from the electric utility, when the generator is on and is providing temporary power. The control capability of a transfer switch may be manual only, or a combination of automatic and manual. The switch transition mode (see below) of a transfer switch may be Open Transition (OT) (the usual type), or Closed Transition (CT).

For example, in a home equipped with a backup generator and an ATS, when an electric utility outage occurs, the ATS will start the backup generator to start. Once the ATS sees that the generator is ready to provide electric power, the ATS breaks the home's connection to the electric utility and connects the generator to the home's main electrical panel. The generator supplies power to the home's electric load, but is not connected to the electric utility. Isolation of the generator from the distribution system is required to protect the generator from overload, and to prevent accidental energization of the service wiring.

When utility power returns for a set time, the transfer switch will transfer back to utility power and command the generator to turn off, after another specified amount of "cool down" time with no load on the generator.

A transfer switch can be set up to provide power to only critical circuits or entire electrical (sub)panels. Some transfer switches allow for load shedding or prioritization of optional circuits, such as heating and cooling equipment. More complex emergency switchgear used in large backup generator installations permits soft loading, allowing load to be smoothly transferred from the utility to the synchronized generators, and back; such installations are useful for reducing peak load demand from a utility.

Types

Open transition

An open transition transfer switch is also called a break before make transfer switch. A break before make transfer switch breaks contact with one source of power before it makes contact with another. It prevents backfeeding from an emergency generator back into the utility line, for example. One example is an open transition automatic transfer switch (ATS). During the split second of the power transfer the flow of electricity is interrupted. Another example is a manual three position circuit breaker, with utility power on one side, the generator on the other, and "off" in the middle, which requires the user to switch through the full disconnect "off" position before making the next connection.

Closed transition

A closed transition transfer switch is also called a make before break transfer switch. In a typical emergency system, there is an inherent momentary interruption of power to the load when it is transferred from one available source to another (keeping in mind that the transfer may be occurring for reasons other than a total loss of power). In most cases this outage is inconsequential, particularly if it is less than 1/6 of a second.

There are some loads, however, that are affected by even the slightest loss of power. There are also operational conditions where it may be desirable to transfer loads with zero interruption of power when conditions permit. For these applications, closed transition transfer switches can be provided. The switch will operate in a make-before-break mode provided both sources are acceptable and synchronized. Typical parameters determining synchronization are: voltage difference less than 5%, frequency difference less than 0.2 Hz, and relative phase angle between the sources of 5 electrical degrees. Since the maximum frequency difference is 0.2 Hz, the engine will generally be required to be controlled by an isochronous governor.

It is generally required that the closed transition, or overlap time, be less than 100 milliseconds. If either source is not present or not acceptable (such as when normal power fails) the switch must operate in a break-before-make mode (standard open transition operation) to ensure no backfeeding occurs.

Closed transition transfer makes code-mandated monthly testing less objectionable because it eliminates the interruption to critical loads, which occur during traditional open transition transfer.

This type of switch may also be referred to as a Static Transfer Switch (STS), as opposed to an Automatic Transfer Switch.

With closed transition transfer, the on-site engine generator set is momentarily connected in parallel with the utility source. This requires getting approval from the local utility company.

Soft loading

A soft-loading transfer switch actively changes the amount of load accepted by the generator.

Applications

Typical load switching applications for which closed transition transfer is desirable include data processing and electronic loads, certain motor and transformer loads, load curtailment systems, or anywhere load interruptions of even the shortest duration are objectionable. It should be understood that a CTTS in a system is not a substitute for a UPS (uninterruptible power supply). In addition to providing line conditioning, a UPS has a built-in stored energy that provides power for a prescribed period of time in the event of a power failure. A CTTS by itself simply assures there will be no momentary loss of power when the load is transferred from one live power source to another.

Home use

Homes with standby generators may use a transfer switch for a few circuits or the whole home. Different models are available, with both manual and automatic transfer. Often small transfer switch systems use circuit breakers with an external operating linkage as the switching mechanism. The linkage operates two circuit breakers in tandem, closing one while opening the other. Manufacturers of transfer switches can provide installation guides to select the size of switch and provide recommended installation procedures. Like all other electrical apparatus, local electrical codes require transfer switches to carry safety approvals. However, some transfer switches are sold via the Internet, and there have been problems with counterfeit circuit breakers.

Vandal resistant switch

Vandal resistant switches (sometimes referred to as vandal proof switches or tamper-proof switches) are electrical switches designed to be installed in a location (or device) and application where they may be subject to vandalism or tampering, as in the case of pedestrian crossing switches, or fraudulent or unauthorized use, as in the case of vending machine switches. Vandal resistant switches that are located on devices that are accessible to the public or which are located outside also have to be able to withstand dust, rain, snow, and frequent operation.

Pushbutton vandal-resistant switches are frequently constructed of stainless steel or other durable metals and mounted into panels or housing boxes made out of strong materials, such as polycarbonate plastic, aluminium, or stainless steel. In some cases, the housing may be 1/4" thick, to protect both the switch and the housing from attempts by vandals to damage the switch or housing using blunt force. The housing for vandal proof switches is often secured using security screws (which cannot be unscrewed with regular screw drivers). The height of buttons in the panel is often minimized by using flush-mounting, to make it more difficult to pry them out, a design technique used in ATM banking machines that are located outside. Some vandal-resistant switches are protected against tampering using other approaches, such as hiding the switches behind a locked or screwed-down door-covered panel, or by requiring a key or passcode before the switch will operate the device.

Characteristics

Electrical characteristics

Vandal resistant switches are often low-voltage, low current, so-called "signal" types intended to trigger a change in state, perhaps from "off" to "on" and vice-versa. The mechanical types often have gold-plated contacts that do not corrode to allow reliable low-power switching. A few types are capable of switching 120 or 220 Volt AC power at several Amperes. These types are better suited to on-off switching of the AC power to a device than the gold-plated contact switches. They often have silver or silver-plated contacts to handle the higher currents that they are specified to switch. Piezo switch types are another of the popular types of vandal resistant switches.

Most, but not all vandal resistant switches are momentary types; that is to say they only open or close a circuit while being depressed and revert to their inactive state when the button is released. Piezoelectric vandal resistant switches usually fall into this category, but generally provide a pulse signal rather than staying continuously activated during the time pressure is applied, unlike their mechanical contact-based counterparts. Latching (Push-on/push-off) type vandal resistant switches with mechanical contacts are also available, and are often used as the power switch for equipment that is used very frequently or which may be subjected to abuse.

Mechanical characteristics

Vandal resistant switches share a few general mechanical characteristics. They are made of durable materials such as machined brass or stainless steel, and often need to be water and dust resistant due to their environments. Some types are potted to make them waterproof. The International Electrotechnical Commission has produced a standard, IEC 60529, which categorizes products' degrees of protection from liquids and dust using IP codes. A DIN extension of the IEC standard, DIN 40050-9 further defines Degree of Protection IP 69K as being able to withstand high-pressure washing or steam cleaning. This capability is needed in some particular applications, such as dairy milking machines, and is provided by some manufacturers' products.

Hidden switches

In some cases, such as equipment used in schools, community centers, or other public places, the equipment is designed so that all of the switches, or some of the switches, are hidden or placed behind a locked cover. Some public address systems are sold in tamper-resistant designs that make it harder for unauthorized members of the public to activate the system or change the settings. Some tamper-proof public address systems are designed so that the switches are at the rear of the unit; only LED lights are on the front of the panel. When the unit is rack-mounted into a wall or rack unit, this means that only official personnel (who are able to access the back of the panel) can change the settings or use the unit. Another variant on this design is to cover the switches with a locked panel. In some cases, such as the sound system in a bar or club, the locked cover may be made from plexiglass, so that the sound engineer can verify the sound system settings and switches (yet at the same time, the locked panel prevents mischief-minded club patrons from tampering or altering the amplifier or equalizer settings).

In some cases, the switches are placed behind a door that is secured with a screw. While this type of "hidden switch" is not locked with a key, it is out of sight and thus it is less likely that most users of the device will try to use them. Screw-on door-covered switches are used on public address equipment that is intended to be rented out to non-professional users. The switches for some settings, such as the on-off switch for the speaker-protection limiter or a low-pitch "rumble filter" (designed to protect speakers from very low sounds), may be hidden behind a screwed-on door or metal plate. Screwed-on covers are also widely used on children's electric and electronic toys, so that a parent can control certain settings such as the maximum speed of a toy electric ride-on car or the maximum volume of a video game.

Locked switches

In some devices, the switch is built into a keyed lock mechanism, which prevents unauthorized use of the device. In this type of vandal-proof system, when the key is turned in the lock, the user can turn the equipment on. Some mobility scooters for disabled people have a locked "on-off" switch, to prevent the scooter from being driven away by vandals or joyriders while it is parked in a public place. A variant of this design

is to use a computerized keypad and a secret code that activates and deactivates the switches. The circular saw systems in major hardware stores use a combination code keypad to prevent store patrons from using the circular saw. The buttons that activate the circular saw do not activate the blade until an authorized user (e.g., a trained store employee) enters the code into the keypad.

Illuminated (indicator) types

Vandal resistant switches (like some other types of switches) can incorporate indicator lights or LEDs to indicate circuit activation, deactivation or fault conditions. LEDs are used for this purpose in this style switch, being available in several colors and operating at low voltages. Single and ring-shaped groups of LEDs can thus show the current status of equipment or machines. In some products the LEDs can have two colors to show multiple status conditions, such as On(e.g. green)/Off(extinguished)/Fault(red).

Non-mechanical types

Although mechanical contact-based switches are most commonly used for general purpose electrical switching, switches that have no moving parts are generally longer-lived. Piezo and capacitive switches are the two most popular non-mechanical switch types currently available. One advantage they have over mechanical contact-based switches is that they have no moving parts to wear out. This makes them capable of lasting for tens of millions of operations. Glass reed switches use a thin metal "reed" that bends when a magnet is brought near it; since the entire unit is sealed in a glass tube, this helps protect the switch from moisture and dust that can damage regular switches.

Applications

- Public interactive kiosks that provide tourist information or government forms
- Elevator buttons and security switches
- Pedestrian crossing signal activation switches
- Intercom "push-to-talk" devices at the entrance to apartment buildings
- Electronic door switches for garages and mechanical gates
- Parking lot ticket machines and computerized ticket paying stations
- Automatic food and drink vending machines
- Public address systems in schools, community centers, and bars
- Rental equipment that may be subjected to heavy use

Chapter-17

Sulfur Hexafluoride Circuit Breaker

High-voltage circuit-breakers have greatly changed since they were first introduced about 40 years ago, and several interrupting principles have been developed that have contributed successively to a large reduction of the operating energy. These breakers are available for indoor or outdoor applications, the latter being in the form of breaker poles housed in ceramic insulators mounted on a structure.

Current interruption in a high-voltage circuit-breaker is obtained by separating two contacts in a medium, such as SF₆, having excellent dielectric and arc quenching properties. After contact separation, current is carried through an arc and is interrupted when this arc is cooled by a gas blast of sufficient intensity.

Gas blast applied on the arc must be able to cool it rapidly so that gas temperature between the contacts is reduced from 20,000 K to less than 2000 K in a few hundred microseconds, so that it is able to withstand the transient recovery voltage that is applied across the contacts after current interruption. Sulphur hexafluoride is generally used in present high-voltage circuit-breakers (of rated voltage higher than 52 kV).

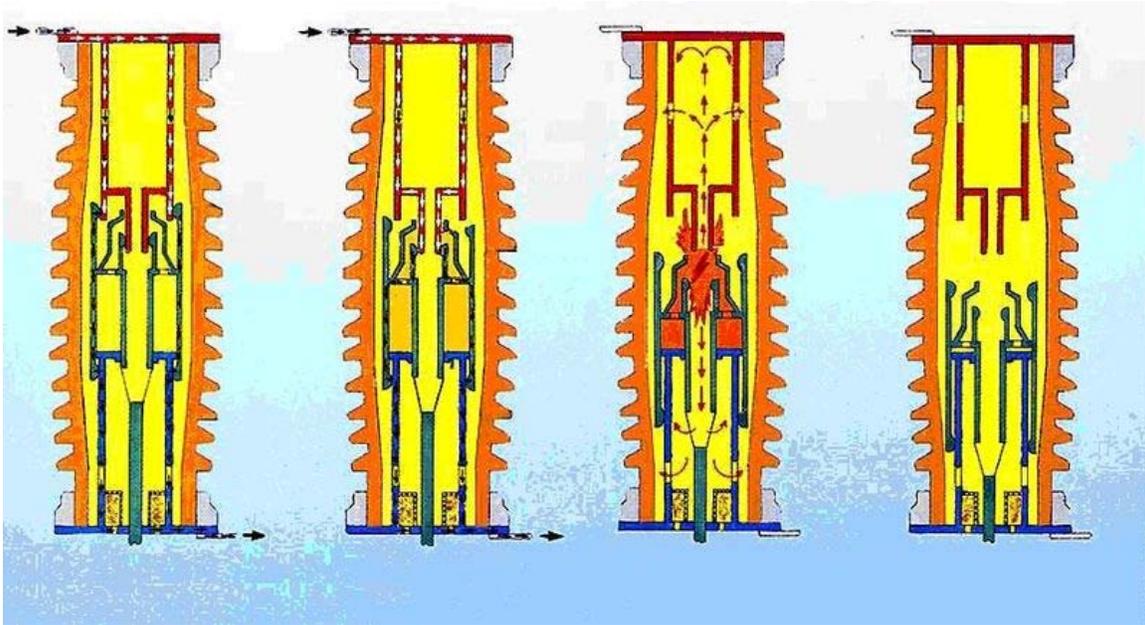
Into the 1980s, the pressure necessary to blast the arc was generated mostly by gas heating using arc energy. It is now possible to use low energy spring-loaded mechanisms to drive high-voltage circuit-breakers up to 800 kV.



An SF₆ circuit breaker rated 115 kV 1200 A installed at a hydroelectric generating station

Brief history

The first patents on the use of SF₆ as an interrupting medium were filed in Germany in 1938 by Vitaly Grosse (AEG) and independently later in the USA in July 1951 by H.J. Lingal, T.E. Browne and A.P. Storm (Westinghouse). The first industrial application of SF₆ for current interruption dates back to 1953. High-voltage 15 kV to 161 kV load switches were developed with a breaking capacity of 600 A. The first high-voltage SF₆ circuit-breaker built in 1956 by Westinghouse, could interrupt 5 kA under 115 kV, but it had 6 interrupting chambers in series per pole. In 1957, the puffer-type technique was introduced for SF₆ circuit breakers where the relative movement of a piston and a cylinder linked to the moving part is used to generate the pressure rise necessary to blast the arc via a nozzle made of insulating material (figure 1). In this technique, the pressure rise is obtained mainly by gas compression. The first high-voltage SF₆ circuit-breaker with a high short-circuit current capability was produced by Westinghouse in 1959. This dead tank circuit-breaker could interrupt 41.8 kA under 138 kV (10,000 MV·A) and 37.6 kA under 230 kV (15,000 MV·A). This performance was already significant, but the three chambers per pole and the high pressure source needed for the blast (1.35 MPa) was a constraint that had to be avoided in subsequent developments. The excellent properties of SF₆ lead to the fast extension of this technique in the 1970s and to its use for the development of circuit breakers with high interrupting capability, up to 800 kV.



The achievement around 1983 of the first single-break 245 kV and the corresponding 420kV to 550 kV and 800 kV, with respectively 2, 3, and 4 chambers per pole, lead to the dominance of SF₆ circuit breakers in the complete range of high voltages.

Several characteristics of SF₆ circuit breakers can explain their success:

- Simplicity of the interrupting chamber which does not need an auxiliary breaking chamber;
- Autonomy provided by the puffer technique;
- The possibility to obtain the highest performance, up to 63 kA, with a reduced number of interrupting chambers;
- Short break time of 2 to 2.5 cycles;
- High electrical endurance, allowing at least 25 years of operation without reconditioning;
- Possible compact solutions when used for "gas insulated switchgear" (GIS) or hybrid switchgear;
- Integrated closing resistors or synchronized operations to reduce switching over-voltages;
- Reliability and availability;
- Low noise levels.

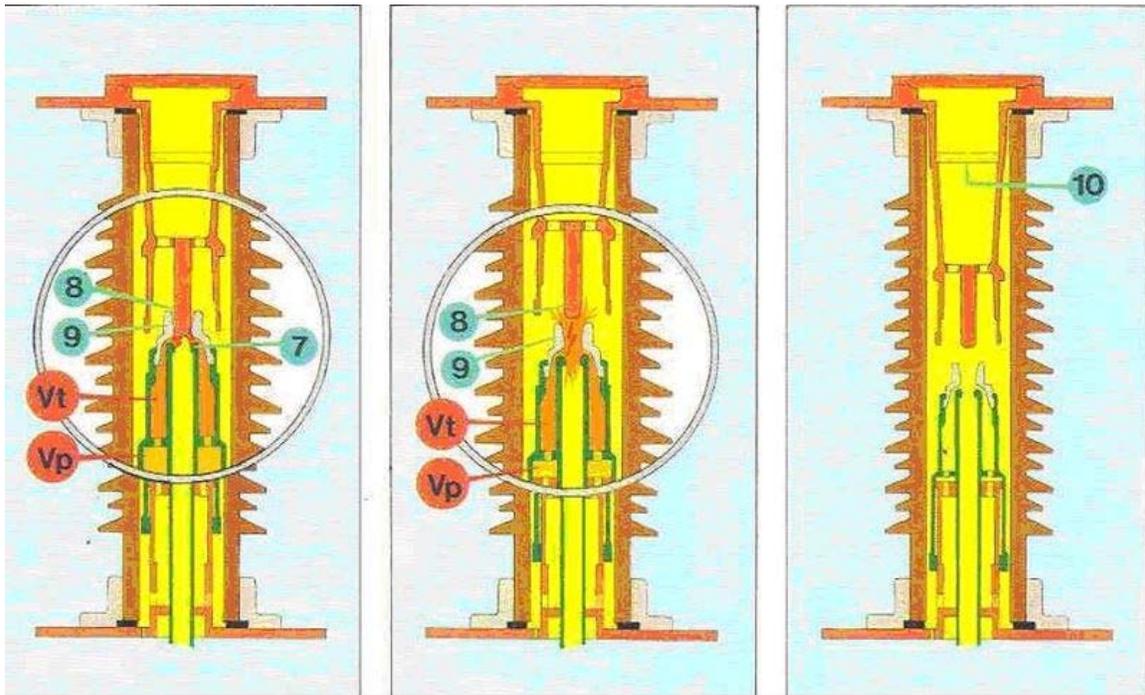
The reduction in the number of interrupting chambers per pole has led to a considerable simplification of circuit breakers as well as the number of parts and seals required. As a direct consequence, the reliability of circuit breakers improved, as verified later on by CIGRE surveys.

Thermal blast chambers

New types of SF₆ breaking chambers, which implement innovative interrupting principles, have been developed over the past 30 years, with the objective of reducing the operating energy of the circuit-breaker. One aim of this evolution was to further increase the reliability by reducing the dynamic forces in the pole. Developments since 1980 have seen the use of the self-blast technique of interruption for SF₆ interrupting chambers.

These developments have been facilitated by the progress made in digital simulations that were widely used to optimize the geometry of the interrupting chamber and the linkage between the poles and the mechanism.

This technique has proved to be very efficient and has been widely applied for high voltage circuit breakers up to 550 kV. It has allowed the development of new ranges of circuit breakers operated by low energy spring-operated mechanisms.

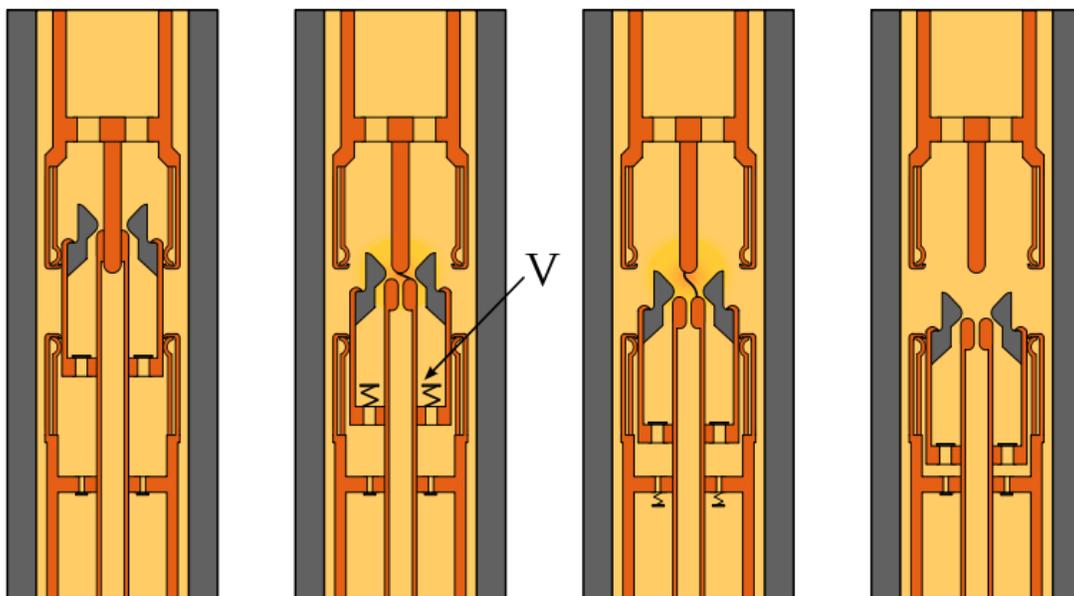


The reduction of operating energy was mainly achieved by the lowering energy used for gas compression and by making increased use of arc energy to produce the pressure necessary to quench the arc and obtain current interruption. Low current interruption, up to about 30% of rated short-circuit current, is obtained by a puffer blast.

Self-blast chambers

Further development in the thermal blast technique was made by the introduction of a valve between the expansion and compression volumes. When interrupting low currents

the valve opens under the effect of the overpressure generated in the compression volume. The blow-out of the arc is made as in a puffer circuit breaker thanks to the compression of the gas obtained by the piston action. In the case of high currents interruption, the arc energy produces a high overpressure in the expansion volume, which leads to the closure of the valve and thus isolating the expansion volume from the compression volume. The overpressure necessary for breaking is obtained by the optimal use of the thermal effect and of the nozzle clogging effect produced whenever the cross-section of the arc significantly reduces the exhaust of gas in the nozzle. In order to avoid excessive energy consumption by gas compression, a valve is fitted on the piston in order to limit the overpressure in the compression to a value necessary for the interruption of low short circuit currents.



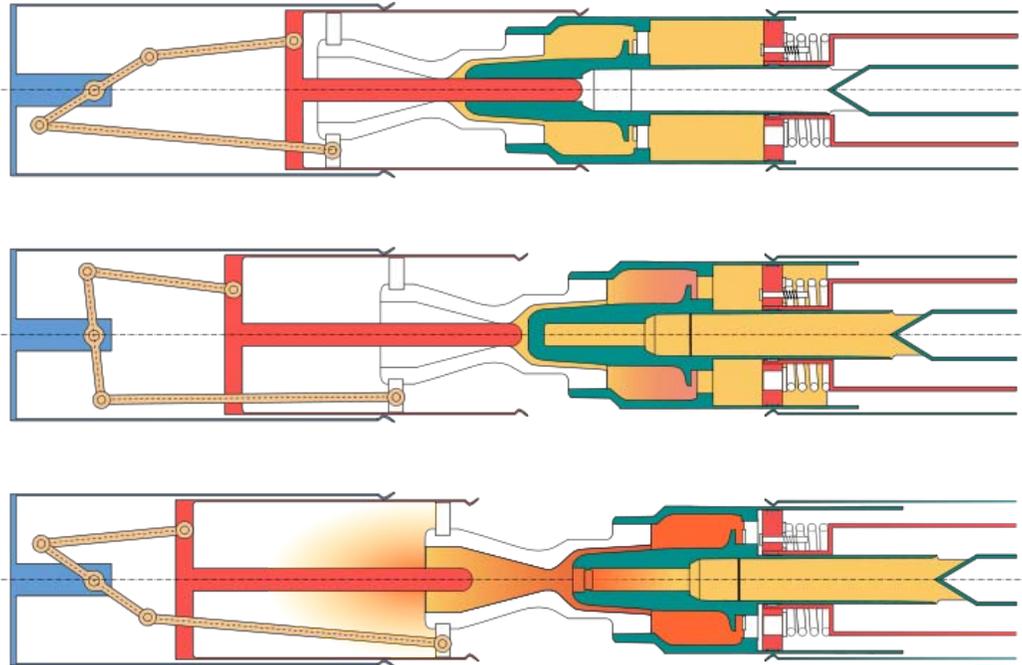
Self-blast circuit breaker chamber (1) closed, (2) interrupting low current, (3) interrupting high current, and (4) open.

This technique, known as “self-blast” has now been used extensively since 1980 for the development of many types of interrupting chambers. The increased understanding of arc interruption obtained by digital simulations and validation through breaking tests, contribute to a higher reliability of these self-blast circuit breakers. In addition the reduction in operating energy, allowed by the self blast technique, leads to longer service life.

Double motion of contacts

An important decrease in operating energy can also be obtained by reducing the kinetic energy consumed during the tripping operation. One way is to displace the two arcing

contacts in opposite directions so that the arc speed is half that of a conventional layout with a single mobile contact.



The thermal and self blast principles have enabled the use of low energy spring mechanisms for the operation of high voltage circuit breakers. They progressively replaced the puffer technique in the 1980s; first in 72.5 kV breakers, and then from 145 kV to 800 kV.

Comparison of single motion and double motion techniques

The double motion technique halves the tripping speed of the moving part. In principle, the kinetic energy could be quartered if the total moving mass was not increased. However, as the total moving mass *is* increased, the practical reduction in kinetic energy is closer to 60%. The total tripping energy also includes the compression energy, which is almost the same for both techniques. Thus, the reduction of the total tripping energy is lower, about 30%, although the exact value depends on the application and the operating mechanism. Depending on the specific case, either the double motion or the single motion technique can be cheaper. Other considerations, such as rationalization of the circuit-breaker range, can also influence the cost.

Thermal blast chamber with arc-assisted opening

In this interruption principle arc energy is used, on the one hand to generate the blast by thermal expansion and, on the other hand, to accelerate the moving part of the circuit

breaker when interrupting high currents. The overpressure produced by the arc energy downstream of the interruption zone is applied on an auxiliary piston linked with the moving part. The resulting force accelerates the moving part, thus increasing the energy available for tripping.

With this interrupting principle it is possible, during high-current interruptions, to increase by about 30% the tripping energy delivered by the operating mechanism and to maintain the opening speed independently of the current. It is obviously better suited to circuit-breakers with high breaking currents such as Generator circuit-breakers.

Generator circuit-breakers

Generator circuit-breakers (GCB's) are connected between a generator and the step-up voltage transformer. They are generally used at the outlet of high power generators (100 MVA to 1800 MVA) in order to protect them in a reliable, fast and economic manner. Such circuit breakers must be able to allow the passage of high permanent currents under continuous service (6.3 kA to 40 kA), and have a high breaking capacity (63 kA to 275 kA).

They belong to the medium voltage range, but the TRV withstand capability required by ANSI/IEEE Standard C37.013 is such that the interrupting principles developed for the high-voltage range must be used. A particular embodiment of the thermal blast technique has been developed and applied to generator circuit-breakers. The self-blast technique described above is also widely used in SF₆ generator circuit breakers, in which the contact system is driven by a low-energy, spring-operated mechanism. An example of such a device is shown in the figure below; this circuit breaker is rated for 17.5 kV and 63 kA.



Generator circuit breaker rated for 17.5 kV and 63 kA

Evolution of tripping energy

The operating energy has been reduced by 5 to 7 times during this period of 30 years. This illustrates well the great progress made in this field of interrupting techniques for high-voltage circuit-breakers.

Future perspectives

In the near future, present interrupting technologies can be applied to circuit-breakers with the higher rated breaking currents (63 kA to 80 kA) required in some networks with increasing power generation.

Self blast or thermal blast circuit breakers are now accepted world wide and they have been in service for high voltage applications for about 25 years by ABB, and later by Areva, starting with the voltage level of 72.5 kV. Today this technique is also available for the voltage levels 420/550/800 kV.

High Power testing

The short-circuit interrupting capability of high-voltage circuit breakers is such that it cannot be demonstrated with a single source able to generate the necessary power. A special scheme is used with a generator that provides the short-circuit current until current interruption and afterwards a voltage source applies the recovery voltage across the terminals of the circuit breaker. Tests are usually performed single-phase but can also be performed three-phase

Issues related to SF₆ Circuit Breakers

The following issues are associated with SF₆ circuit breakers

Greenhouse gas

SF₆ is the most potent greenhouse gas that the Intergovernmental Panel on Climate Change has evaluated. It has a global warming potential that is 23,900 times worse than CO₂. SF₆ has been classified as a restricted gas under the Kyoto Protocol.

Toxic lower order gases

When an arc is formed in SF₆ gas small quantities of lower order gases are formed. Some of these byproducts are toxic and can cause irritation to eyes and respiratory system.

Oxygen displacement

SF₆ is heavier than air so care must be taken when entering low confined spaces due to the risk of oxygen displacement.

Alternatives to SF₆ Circuit Breakers

Circuit Breakers are usually classed on their insulating medium. The follow types of circuit breakers may be an alternative to SF₆ types.

- Air blast
- Oil
- Vacuum