



# Electrical Systems & Standards

Buck Buford

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## Chapter 1

# Electrical Element

**Electrical elements** are conceptual abstractions representing idealized electrical components, such as resistors, capacitors, and inductors, used in the analysis of electrical networks. Any electrical network can be analysed as multiple, interconnected electrical elements in a schematic diagram or circuit diagram, each of which affects the voltage in the network or current through the network. These ideal electrical elements represent real, physical electrical or electronic components but they do not exist physically and they are assumed to have ideal properties according to a lumped element model, while components are objects with less than ideal properties, a degree of uncertainty in their values and some degree of nonlinearity, each of which may require a combination of multiple electrical elements in order to approximate its function.

Circuit analysis using electric elements is useful for understanding many practical electrical networks using components. By analyzing the way a network is affected by its individual elements it is possible to estimate how a real network will behave.

### ***One-port elements***

Only nine types of two-terminal elements, five passive and four active, are required to model any electrical component or circuit. Each element is defined by a relation between the state variables of the network: current,  $I$ ; voltage,  $V$ , charge,  $Q$ ; and magnetic flux,  $\Phi$ .

### **Passive elements**

- *Resistors* with resistance  $R$ , measured in ohms – produces a voltage proportional to the current flowing through the element. Relates voltage and current according to the relation  $dV = R dI$ .
  - linear (resistor)
  - nonlinear (varistor)
  - time-dependent nonlinear (memristor)

- *Capacitors* with capacitance  $C$ , measured in farads – produces a current proportional to the rate of change of voltage across the element. Relates charge and voltage according to the relation  $dQ = C dV$ .
  - linear (capacitor)
  - nonlinear (varactor)
  - time-dependent nonlinear (memcapacitor)
- *Inductors* with inductance  $L$ , measured in henries – produces the magnetic flux proportional to the rate of change of current through the element. Relates flux and current according to the relation  $d\Phi = L dI$ .
  - linear (inductor)
  - nonlinear inductor
  - time-dependent nonlinear (meminductor)

The passive electrical elements and their variations are shown below in a form of a table where the rows represent the electrical properties and the columns represent the variations of these properties.

	<b>Linear</b>	<b>Nonlinear</b>	<b>Memory</b>
<b>Resistance</b>	Resistor	Varistor	Memristor
<b>Capacitance</b>	Capacitor	Varactor	Memcapacitor
<b>Inductance</b>	Inductor	NL inductor	Meminductor

### The fourth passive element

In reality, all circuit elements are non-linear and can only be approximated to linear over a certain range. To more exactly describe the passive elements, their constitutive relation is used instead of simple proportionality. From any two of the circuit variables there are six constitutive relations that can be formed. From this it is supposed that there is a theoretical fourth passive element since there are only five elements in total found in linear network analysis. This additional element is called *memristor*. It only has any meaning as a time-dependent non-linear element; as a time-independent linear element it reduces to a regular resistor. The constitutive relations of the passive elements are given by;

- Resistance: constitutive relation defined as  $f(V,I) = 0$ .
- Capacitance: constitutive relation defined as  $f(V,Q) = 0$ .
- Inductance: constitutive relation defined as  $f(\Phi,I) = 0$ .
- Memristance: constitutive relation defined as  $f(\Phi,Q) = 0$ .

where  $f(x,y)$  is an arbitrary function of two variables.

In some special cases the constitutive relation simplifies to a function of one variable. This is the case for all linear elements, but also' for example, an ideal diode, which in circuit theory terms is a non-linear resistor, has a constitutive relation of the form  $V = f(I)$ .

The fourth passive element, the memristor, is proposed by Leon Chua in a 1971 paper, but a physical component demonstrating memristance was not created until thirty-seven years later. It was reported on April 30, 2008, that a working memristor had been developed by a team at HP Labs led by scientist R. Stanley Williams. With the advent of the memristor, each pairing of the four variables can now be related. Although memristors are analog memory elements, they are able to store one bit of non-volatile memory. They may see application in programmable logic, signal processing, neural networks, and control systems, among other fields. Because memristors are time-variant by definition, they are not included in linear time-invariant (LTI) circuit models.

## Sources

- Current source, measured in amperes – produces a current in a conductor. Affects charge according to the relation  $dQ = -I dt$ .
- Voltage source, measured in volts – produces a potential difference between two points. Affects magnetic flux according to the relation  $d\Phi = V dt$ .

$\Phi$  in this relationship does not necessarily represent anything physically meaningful. In the case of the current generator,  $Q$ , the time integral of current, represents the quantity of electric charge physically delivered by the generator. Here  $\Phi$  is the time integral of voltage but whether or not that represents a physical quantity depends on the nature of the voltage source. For a voltage generated by magnetic induction it is meaningful, but for an electrochemical source, or a voltage that is the output of another circuit, no physical meaning is attached to it.

## Controlled sources

- Voltage-controlled voltage source (VCVS) Generates a voltage based on another voltage with respect to a specified gain. (has infinite input impedance and zero output impedance).
- Voltage-controlled current source (VCCS) Generates a current based on a voltage with respect to a specified gain, used to model field-effect transistors and vacuum tubes (has infinite input impedance and infinite output impedance).
- Current-controlled voltage source (CCVS) Generates a voltage based on an input current with respect to a specified gain. (has zero input impedance and zero output impedance).
- Current-controlled current source (CCCS) Generates a current based on an input current and a specified gain. Used to model bipolar junction transistors. (Has zero input impedance and infinite output impedance).

There are also two special non-linear elements which are sometimes used in analysis but which are not the ideal counterpart of any real component:

- Nullator: defined as  $V = I = 0$
- Norator: defined as an element which places no restrictions on voltage and current whatsoever.

These are sometimes used in models of components with more than two terminals: transistors for instance.

## **Two-port elements**

All the above are two-terminal, or one-port elements. There are two lossless, passive, linear two-port elements that are normally introduced into network analysis. Their constitutive relations in matrix notation are;

Transformer

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 0 & n \\ -n & 0 \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

Gyrator

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 0 & -r \\ r & 0 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

The transformer maps a voltage at one port to a voltage at the other in a ratio of  $n$ . The current between the same two port is mapped by  $1/n$ . The gyrator, on the other hand, maps a voltage at one port to a current at the other. Likewise, currents are mapped to voltages. The quantity  $r$  in the matrix is in units of resistance. The gyrator is a necessary element in analysis because it is not reciprocal. Networks built from the basic linear elements only are obliged to be reciprocal and so cannot be used by themselves to represent a non-reciprocal system. It is not essential, however, to have both the transformer and gyrator. Two gyrators in cascade are equivalent to a transformer but the transformer is usually retained for convenience. Introduction of the gyrator also makes either capacitance or inductance non-essential since a gyrator terminated with one of these at port 2 will be equivalent to the other at port 1.

## **Examples**

The following are examples of representation of components by way of electrical elements.

- On a first degree of approximation, a battery is represented by a voltage source. A more refined model also includes a resistance in series with the voltage source, to represent the battery's internal resistance (which results in the battery heating and the voltage dropping when in use). A current source in parallel may be added to represent its leakage (which discharges the battery over a long period of time).
- On a first degree of approximation, a resistor is represented by a resistance. A more refined model also includes a series inductance, to represent the effects of its lead inductance (resistors constructed as a spiral have more significant inductance). A capacitance in parallel may be added to represent the capacitive effect of the proximity of the resistor leads to each other. A wire can be represented as a low-value resistor

- Current sources are more often used when representing semiconductors. For example, on a first degree of approximation, a bipolar transistor may be represented by a variable current source that is controlled by the input voltage.

## Chapter 2

# Electric Current

**Electric current** is a flow of electric charge through a medium. This charge is typically carried by moving electrons in a conductor such as wire. It can also be carried by ions in an electrolyte, or by both ions and electrons in a plasma.

The SI unit for measuring the rate of flow of electric charge is the ampere, which is charge flowing through some surface at the rate of one coulomb per second. Electric current is measured using an ammeter.

### ***Symbol***

The conventional symbol for current is  $I$ , which may seem puzzling. It originates from the French phrase *intensité de courant*, or in English *current intensity*. This phrase is frequently used when discussing the value of an electric current, especially in older texts; modern practice often shortens this to simply *current* but *current intensity* is still used in many recent textbooks. The  $I$  symbol was used by André-Marie Ampère himself, after whom the unit of electric current is named, in formulating the eponymous Ampère's force law which he discovered in 1820. The notation travelled from France to England where it became standard, although at least one journal did not change from using  $C$  to  $I$  until 1896.

### ***Conduction mechanisms in various media***

In metallic solids, electricity flows by means of electrons, from lower to higher electrical potential. In other media, any stream of charged objects may constitute an electric current. To provide a definition of current that is independent of the type of charge carriers flowing, *conventional current* is defined to flow in the same direction as positive charges. So in metals where the charge carriers (electrons) are negative, conventional current flows in the opposite direction as the electrons. In conductors where the charge carriers are positive, conventional current flows in the same direction as the charge carriers.

In a vacuum, a beam of ions or electrons may be formed. In other conductive materials, the electric current is due to the flow of both positively and negatively charged particles at the same time. In still others, the current is entirely due to positive charge flow. For example, the electric currents in electrolytes are flows of electrically charged atoms (ions), which exist in both positive and negative varieties. In a common lead-acid electrochemical cell, electric currents are composed of positive hydrogen ions (protons) flowing in one direction, and negative sulfate ions flowing in the other. Electric currents in sparks or plasma are flows of electrons as well as positive and negative ions. In ice and in certain solid electrolytes, the electric current is entirely composed of flowing ions. In a semiconductor it is sometimes useful to think of the current as due to the flow of positive "holes" (the mobile positive charge carriers that are places where the semiconductor crystal is missing a valence electron). This is the case in a p-type semiconductor.

## Metals

A solid conductive metal contains mobile, or free electrons, originating in the conduction electrons. These electrons are bound to the metal lattice but no longer to any individual atom. Even with no external electric field applied, these electrons move about randomly due to thermal energy but, on average, there is zero net current within the metal. Given a surface through which a metal wire passes, the number of electrons moving from one side to the other in any period of time is on average equal to the number passing in the opposite direction. As George Gamow put in his science-popularizing book, *One, Two, Three...Infinity* (1947), "The metallic substances differ from all other materials by the fact that the outer shells of their atoms are bound rather loosely, and often let one of their electrons go free. Thus the interior of a metal is filled up with a large number of unattached electrons that travel aimlessly around like a crowd of displaced persons. When a metal wire is subjected to electric force applied on its opposite ends, these free electrons rush in the direction of the force, thus forming what we call an electric current."

When a metal wire is connected across the two terminals of a DC voltage source such as a battery, the source places an electric field across the conductor. The moment contact is made, the free electrons of the conductor are forced to drift toward the positive terminal under the influence of this field. The free electrons are therefore the charge carrier in a typical solid conductor. For an electric current of 1 ampere, 1 coulomb of electric charge (which consists of about  $6.242 \times 10^{18}$  elementary charges) drifts every second through any plane through which the conductor passes.

For a steady flow of charge through a surface, the current  $I$  in amperes can be calculated with the following equation:

$$I = \frac{Q}{t},$$

where  $Q$  is the electric charge transferred through the surface over some time  $t$ . If  $Q$  and  $t$  are measured in coulombs and seconds respectively,  $I$  is in amperes.

More generally, electric current can be represented as the rate at which charge flows through a given surface as:

$$I = \frac{dQ}{dt} .$$

## **Electrolytes**

Electric currents in electrolytes are flows of electrically charged particles (ions). For example, if an electric field is placed across a solution of  $\text{Na}^+$  and  $\text{Cl}^-$  (and conditions are right) the sodium ions move towards the negative electrode (cathode), while the chloride ions move towards the positive electrode (anode). Reactions take place at both electrode surfaces, absorbing each ion.

Water-ice and certain solid electrolytes called proton conductors contain positive hydrogen ions or "protons" which are mobile. In these materials, electric currents are composed of moving protons, as opposed to the moving electrons found in metals.

In certain electrolyte mixtures, brightly-colored ions form the moving electric charges. The slow migration of these ions means that the current is visible.

## **Gases and plasmas**

In air and other ordinary gases below the breakdown field, the dominant source of electrical conduction is via a relatively small number of mobile ions produced by radioactive gases, ultraviolet light, or cosmic rays. Since the electrical conductivity is low, gases are dielectrics or insulators. However, once the applied electric field approaches the breakdown value, free electrons become sufficiently accelerated by the electric field to create additional free electrons by colliding, and ionizing, neutral gas atoms or molecules in a process called avalanche breakdown. The breakdown process forms a plasma that contains a significant number of mobile electrons and positive ions, causing it to behave as an electrical conductor. In the process, it forms a light emitting conductive path, such as a spark, arc or lightning.

Plasma is the state of matter where some of the electrons in a gas are stripped or "ionized" from their molecules or atoms. A plasma can be formed by high temperature, or by application of a high electric or alternating magnetic field as noted above. Due to their lower mass, the electrons in a plasma accelerate more quickly in response to an electric field than the heavier positive ions, and hence carry the bulk of the current.

## **Vacuum**

Since a "perfect vacuum" contains no charged particles, it normally behaves as perfect insulator. However, metal electrode surfaces can cause a region of the vacuum to become conductive by injecting free electrons or ions through either field electron emission or thermionic emission. Thermionic emission occurs when the thermal energy exceeds the

metal's work function, while field electron emission occurs when the electric field at the surface of the metal is high enough to cause tunneling, which results in the ejection of free electrons from the metal into the vacuum. Externally heated electrodes are often used to generate an electron cloud as in the filament or indirectly heated cathode of vacuum tubes. Cold electrodes can also spontaneously produce electron clouds via thermionic emission when small incandescent regions (called **cathode spots** or **anode spots**) are formed. These are incandescent regions of the electrode surface that are created by a localized high current flow. These regions may be initiated by field electron emission, but are then sustained by localized thermionic emission once a vacuum arc forms. These small electron-emitting regions can form quite rapidly, even explosively, on a metal surface subjected to a high electrical field. Vacuum tubes and sprytrons are some of the electronic switching and amplifying devices based on vacuum conductivity.

### ***Current density and Ohm's law***

Current density is a measure of the density of an electric current. It is defined as a vector whose magnitude is the electric current per cross-sectional area. In SI units, the current density is measured in amperes per square meter.

$$I = \vec{J} \cdot \vec{A}$$

where  $I$  is current in the conductor,  $\mathbf{J}$  is the current density, and  $\mathbf{A}$  is the cross-sectional area. The dot product of the two vector quantities ( $\mathbf{A}$  and  $\mathbf{J}$ ) is a scalar that represents the electric current.

Current density (current per unit area)  $J$  in a material is proportional to the conductivity  $\sigma$  and electric field  $E$  in the medium:

$$J = \sigma E$$

Instead of conductivity, reciprocal quantity called resistivity  $\rho$ , can be used:

$$J = \frac{E}{\rho}$$

Conduction in semiconductor devices may occur by a combination of electric field (drift) and diffusion, which is proportional to diffusion constant  $D$  and charge density  $\alpha_q$ . The current density is then:

$$J = \sigma E + Dq\nabla n,$$

with  $q$  being the elementary charge and  $n$  the electron density. The carriers move in the direction of decreasing concentration, so for electrons a positive current results for a positive density gradient. If the carriers are holes, replace electron density  $n$  by the negative of the hole density  $p$ .

In linear anisotropic materials,  $\sigma$ ,  $\rho$  and  $D$  are tensors.

In linear materials such as metals, and under low frequencies, the current density across the conductor surface is uniform. In such conditions, Ohm's law states that the current is directly proportional to the potential difference between two ends (across) of that metal (ideal) resistor (or other ohmic device):

$$I = \frac{V}{R},$$

where  $I$  is the current, measured in amperes;  $V$  is the potential difference, measured in volts; and  $R$  is the resistance, measured in ohms. The letter  $I$  stands for the German word, "Intensität" meaning "Intensity". For alternating currents, especially at higher frequencies, skin effect causes the current to spread unevenly across the conductor cross-section, with higher density near the surface, thus increasing the apparent resistance.

### **Drift speed**

The mobile charged particles within a conductor move constantly in random directions, like the particles of a gas. In order for there to be a net flow of charge, the particles must also move together with an average drift rate. Electrons are the charge carriers in metals and they follow an erratic path, bouncing from atom to atom, but generally drifting in the opposite direction of the electric field. The speed at which they drift can be calculated from the equation:

$$I = nAvQ,$$

where

$I$  is the electric current

$n$  is number of charged particles per unit volume (or charge carrier density)

$A$  is the cross-sectional area of the conductor

$v$  is the drift velocity, and

$Q$  is the charge on each particle.

Electric currents in solids typically flow very slowly. For example, in a copper wire of cross-section  $0.5 \text{ mm}^2$ , carrying a current of  $5 \text{ A}$ , the *drift velocity* of the electrons is on the order of a millimetre per second. To take a different example, in the near-vacuum inside a cathode ray tube, the electrons travel in near-straight lines at about a tenth of the speed of light.

Any accelerating electric charge, and therefore any changing electric current, gives rise to an electromagnetic wave that propagates at very high speed outside the surface of the conductor. This speed is usually a significant fraction of the speed of light, as can be deduced from Maxwell's Equations, and is therefore many times faster than the drift velocity of the electrons. For example, in AC power lines, the waves of electromagnetic

energy propagate through the space between the wires, moving from a source to a distant load, even though the electrons in the wires only move back and forth over a tiny distance.

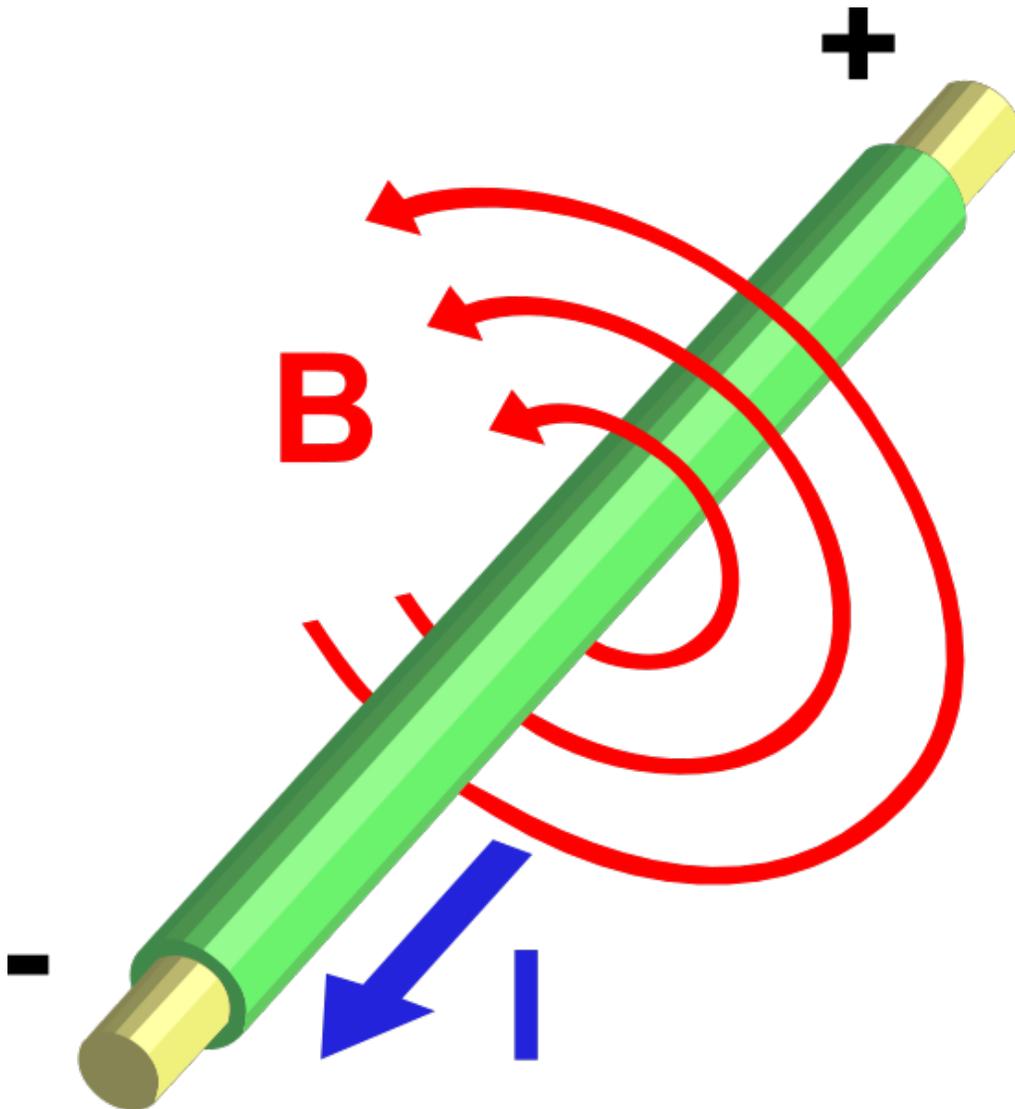
The ratio of the speed of the electromagnetic wave to the speed of light in free space is called the velocity factor, and depends on the electromagnetic properties of the conductor and the insulating materials surrounding it, and on their shape and size.

The magnitudes (but, not the natures) of these three velocities can be illustrated by an analogy with the three similar velocities associated with gases.

- The low drift velocity of charge carriers is analogous to air motion; in other words, winds.
- The high speed of electromagnetic waves is roughly analogous to the speed of sound in a gas (these waves move through the medium much faster than any individual particles do)
- The random motion of charges is analogous to heat - the thermal velocity of randomly vibrating gas particles.

This analogy is extremely simplistic and incomplete: The rapid propagation of a sound wave doesn't impart any change in the air molecules' drift velocity, whereas EM waves do carry the energy to propagate the actual current at a rate which is much, much higher than the electrons' drift velocity. To illustrate the difference: The sound and the change in the air's drift velocity (the force of the wind gust) cross distance at rates equaling the speeds of sound and of mechanical transmission of force (**not higher** than rate of drift velocity); while a change in an EM field and the **change** in current (electrons' drift velocity) both propagate across distance at rates **much higher** than the actual drift velocity. You can hear wind much earlier than the force of the gust reaches you, but you don't observe a change in an EM field earlier than you can observe the change of current.

## *Electromagnetism*



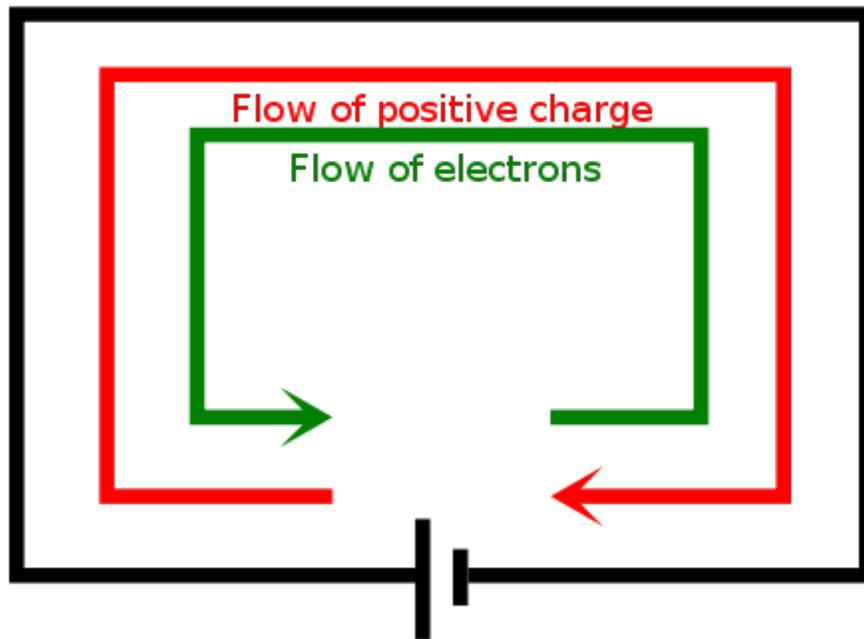
According to Ampère's law, an electric current produces a magnetic field.

Electric current produces a magnetic field. The magnetic field can be visualized as a pattern of circular field lines surrounding the wire.

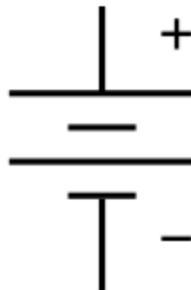
Electric current can be directly measured with a galvanometer, but this method involves breaking the electrical circuit, which is sometimes inconvenient. Current can also be measured without breaking the circuit by detecting the magnetic field associated with the current. Devices used for this include Hall effect sensors, current clamps, current transformers, and Rogowski coils.

The theory of Special Relativity allows one to transform the magnetic field into a static electric field for an observer moving at the same speed as the charge in the diagram. The amount of current is particular to a reference frame.

### **Conventions**



The electrons, the charge carriers in an electrical circuit, flow in the opposite direction of the *conventional* electric current.



The symbol for a battery in a circuit diagram.

A flow of positive charges gives the same *electric* current as a flow of negative charges in the opposite direction. Since current can be the flow of either positive or negative charges, or both, a convention for the direction of current which is independent of the

type of charge carriers is needed. Therefore the direction of *conventional current* is defined to be the direction of the flow of positive charges.

In metals, which make up the wires and other conductors in most electrical circuits, the positive charges are immobile, and only the negatively charged electrons flow. Because the electron carries negative charge, the *electron* motion in a metal conductor is in the direction opposite to that of conventional (or *electric*) current.

## **Reference direction**

When analyzing electrical circuits, the actual direction of current through a specific circuit element is usually unknown. Consequently, each circuit element is assigned a current variable with an arbitrarily chosen *reference direction*. When the circuit is solved, the circuit element currents may have positive or negative values. A negative value means that the actual direction of current through that circuit element is opposite that of the chosen reference direction. In electronic circuits the reference current directions are usually chosen so that all currents flow toward ground. This often matches conventional current direction, because in many circuits the power supply voltage is positive with respect to ground.

## **Occurrences**

Natural examples include lightning and the solar wind, the source of the polar auroras (the aurora borealis and aurora australis). The artificial form of electric current is the flow of conduction electrons in metal wires, such as the overhead power lines that deliver electrical energy across long distances and the smaller wires within electrical and electronic equipment. In electronics, other forms of electric current include the flow of electrons through resistors or through the vacuum in a vacuum tube, the flow of ions inside a battery or a neuron, and the flow of holes within a semiconductor.

## **Current Measurement**

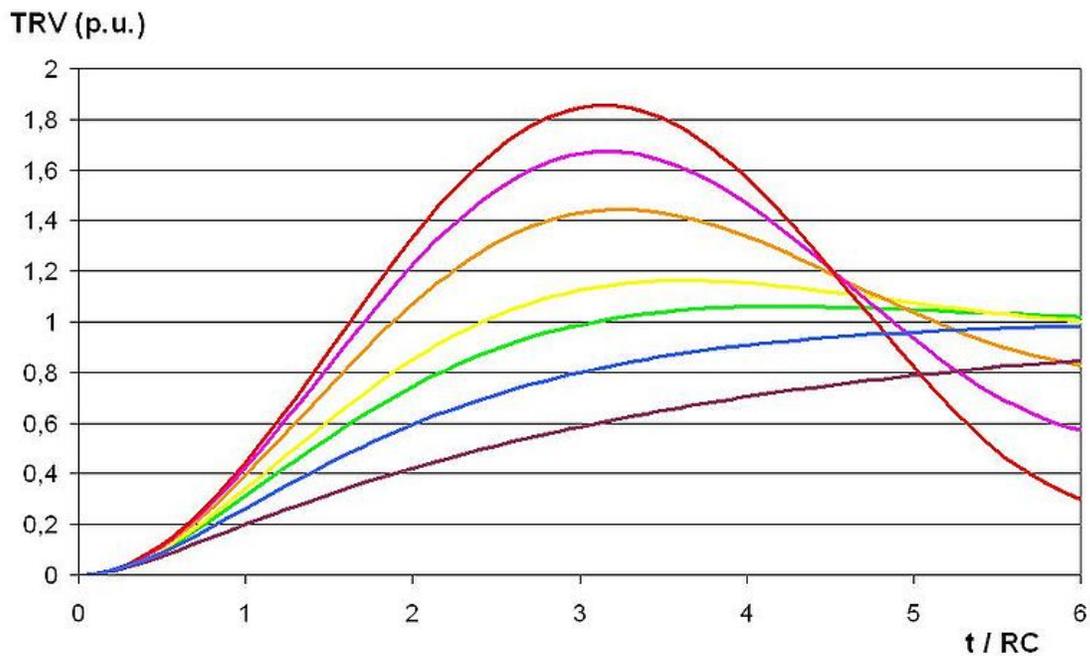
Current can be measured using an ammeter.

At the circuit level there are various techniques that can be used to measure current:

- Shunt resistor
- Hall effect current sensor transducers
- Transformer (however dc cannot be measured)
- Magnetoresistive Field Sensors

## Chapter 3

# Transient Recovery Voltage



Examples of TRV waveshapes

A **transient recovery voltage** (or TRV) for high-voltage circuit breakers is the voltage that appears across the terminals after current interruption. It is a critical parameter for fault interruption by a high-voltage circuit breaker, its characteristics (amplitude, rate of rise) can lead either to a successful current interruption or to a failure (called reignition or restrike).

The TRV is dependent on the characteristics of the system connected on both terminals of the circuit-breaker, and on the type of fault that this circuit breaker has to interrupt (single, double or three-phase faults, grounded or ungrounded fault ..).

Characteristics of the system include:

- type of neutral (effectively grounded, ungrounded, solidly grounded ..)
- type of load (capacitive, inductive, resistive)
- type of connection: cable connected, line connected..

The most severe TRV is applied on the first pole of a circuit-breaker that interrupts current (called the first-pole-to-clear in a three-phase system). The parameters of TRVs are defined in international standards such as IEC and IEEE (or ANSI).

### **Capacitive load**

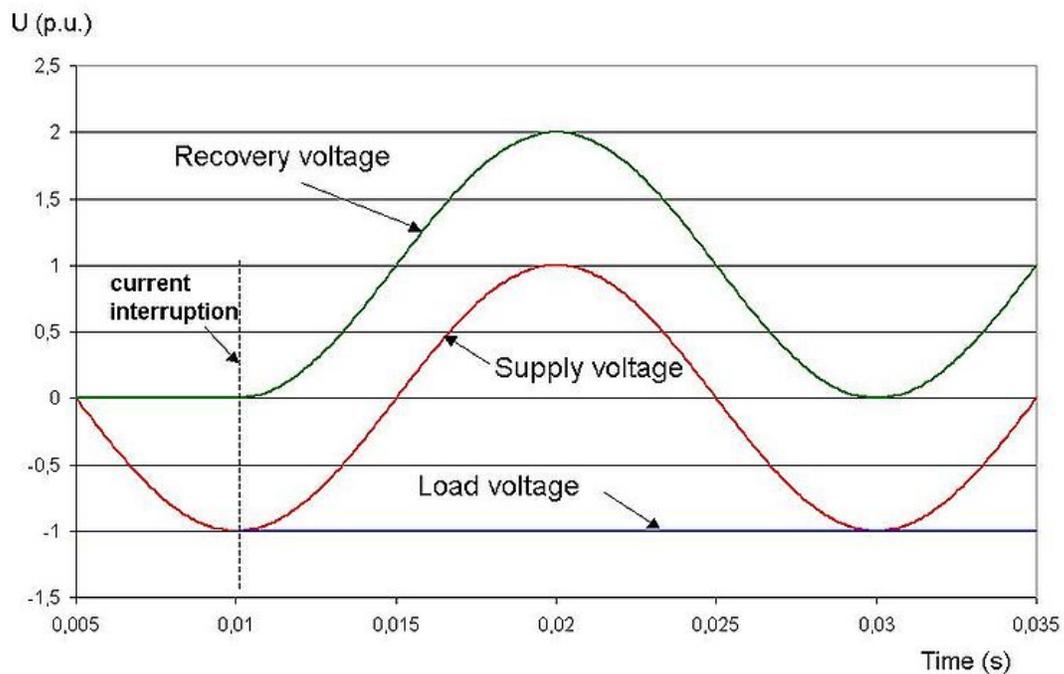


Figure 1 - Recovery voltage in case of a capacitive load

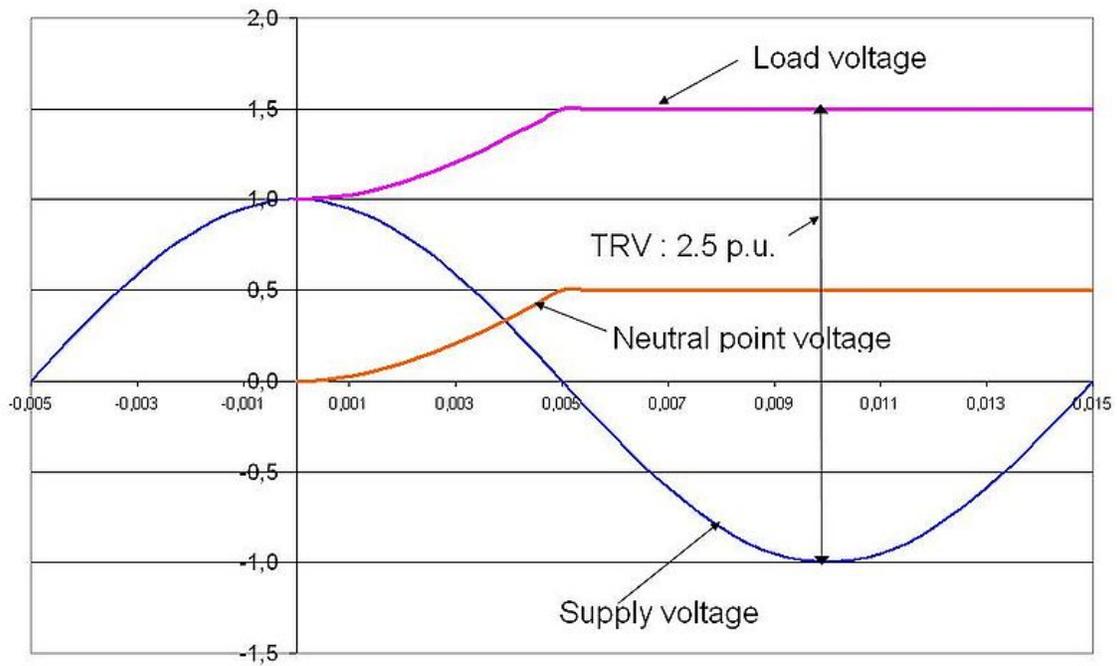


Figure 2 - Voltages on terminals of the first pole that clears three-phase capacitive currents in a system with isolated neutral

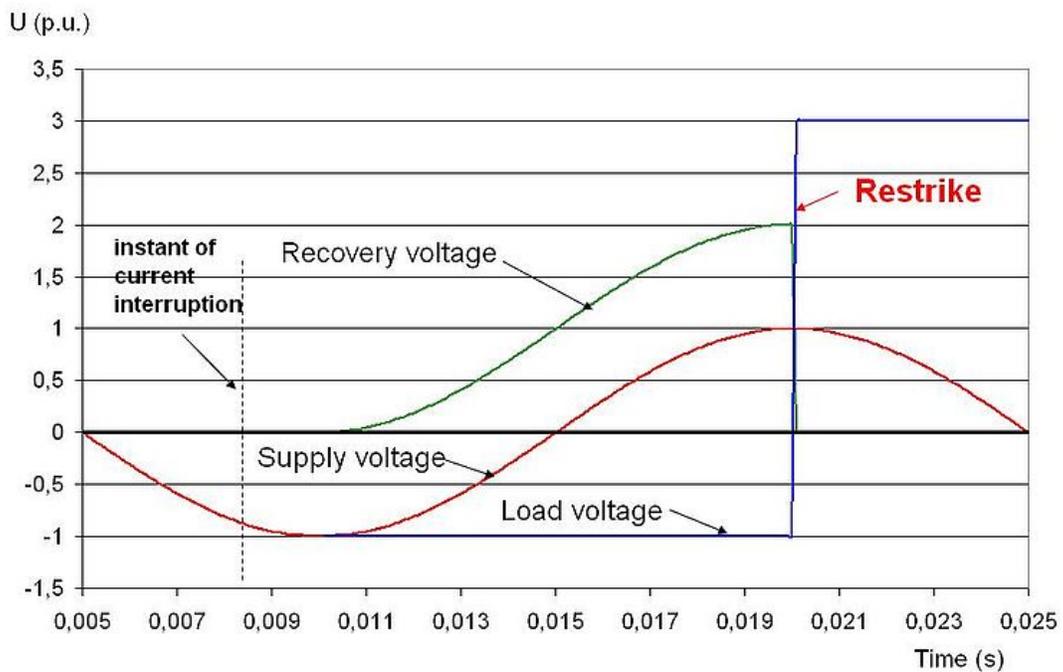


Figure 3 - Evolution of voltages with restriking occurring a half cycle after current interruption, in the case of single-phase capacitive current switching

Typical cases of capacitive loads are unloaded lines and capacitor banks.

## ***Inductive circuit***

### **Terminal fault**

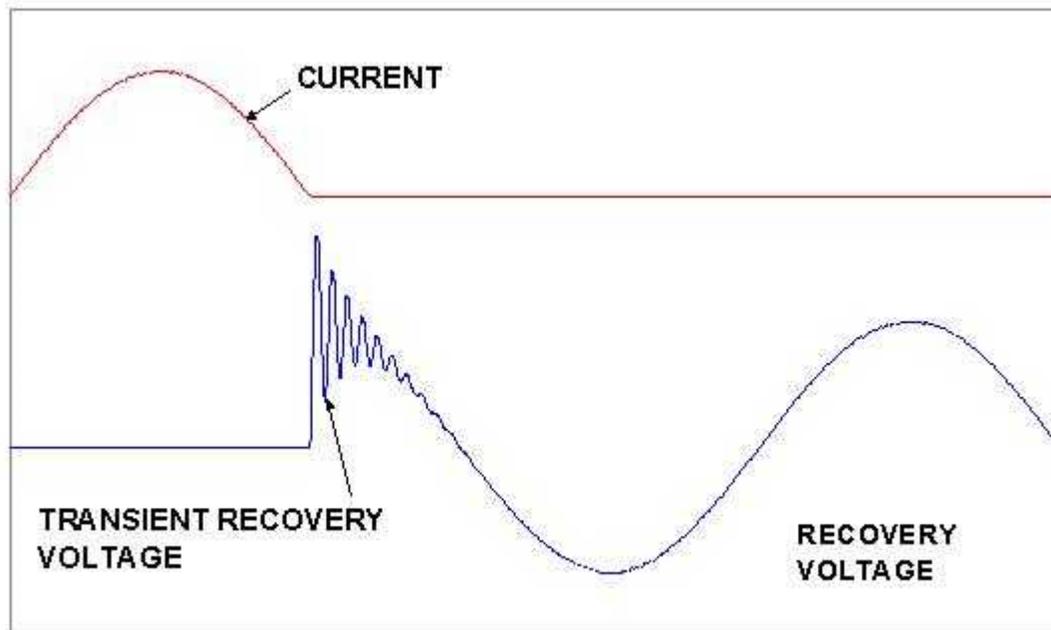


Figure 4 - TRV in inductive circuit

A terminal fault is a fault that occurs at the circuit breaker terminals. The circuit breaker interrupts a short-circuit at current zero, at this instant the supply voltage is maximum and the recovery voltage tends to reach the supply voltage with a high frequency transient. The normalized value of the overshoot or amplitude factor is 1.4.

### **Short-line-fault**

A short-line-fault is a fault that occurs on a line a few hundred meters to several kilometers down the line from the circuit breaker terminal. As shown on Figure 5, the TRV is characterized, in its initial part, by a steep rate-of-rise due to a high-frequency oscillation produced by travelling waves that travel on the line with positive and negative reflections at the circuit breaker terminal and at the fault point, respectively. The superposition of these travelling waves gives the voltage profiles on the line shown on Figures 6 to 14 with, on the horizontal axis, the circuit breaker terminal position on the left and the short-circuit point on the right.

The voltage profile is given at different instants after current interruption, where  $T_L$  is time needed for a wave to travel from the circuit breaker down the line and back to the circuit breaker terminal.

Figure 15 shows, as function of time, the variation of voltage on the line-side terminal of the circuit breaker. The voltage variation is two times the initial voltage if losses are neglected, in reality it is approximately 1.6 times the initial voltage. The triangular waveshape of voltage on the line-side terminal, combined with a supply-side voltage variation at a lower frequency, produces the sawtooth variation of TRV shown on Figure 5.

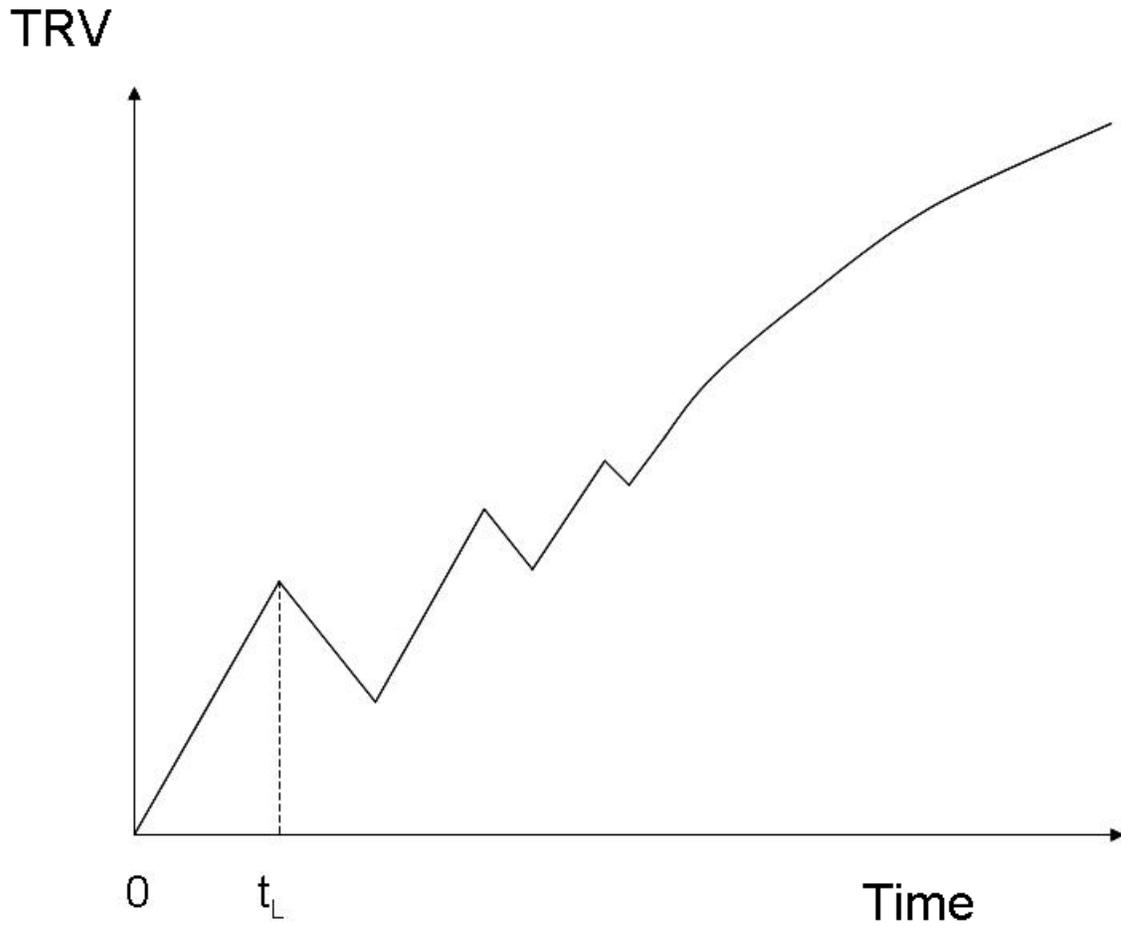


Figure 5 - TRV in case of short-line-fault.

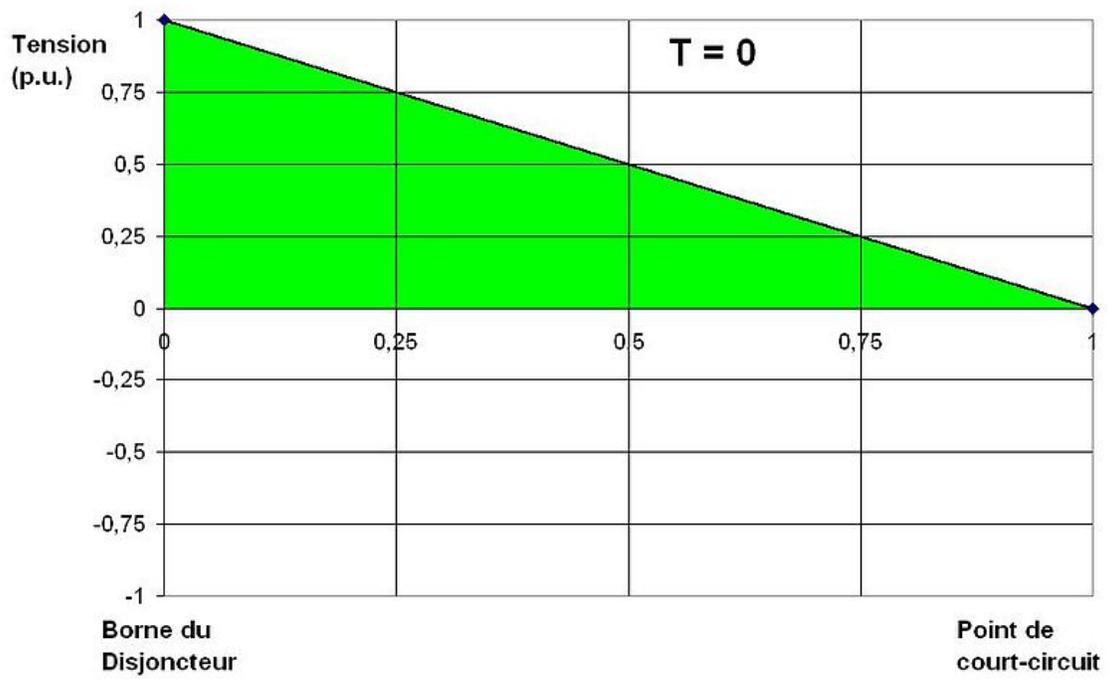


Figure 6 - Instant 0 (instant of current interruption)

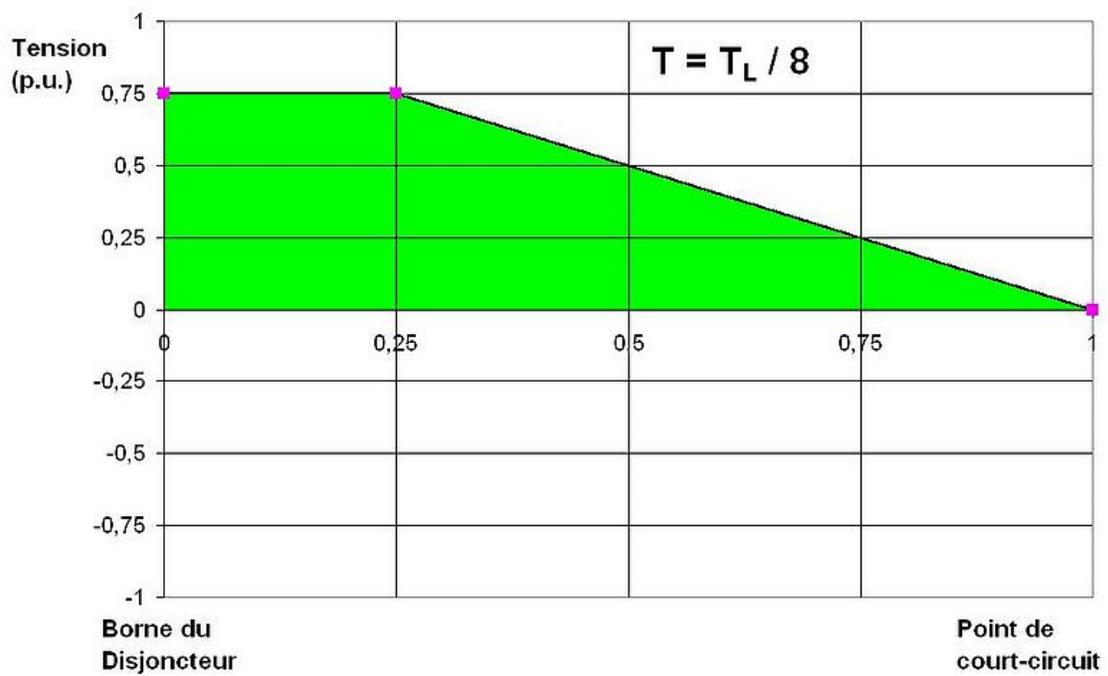


Figure 7 - Instant  $T_L/8$

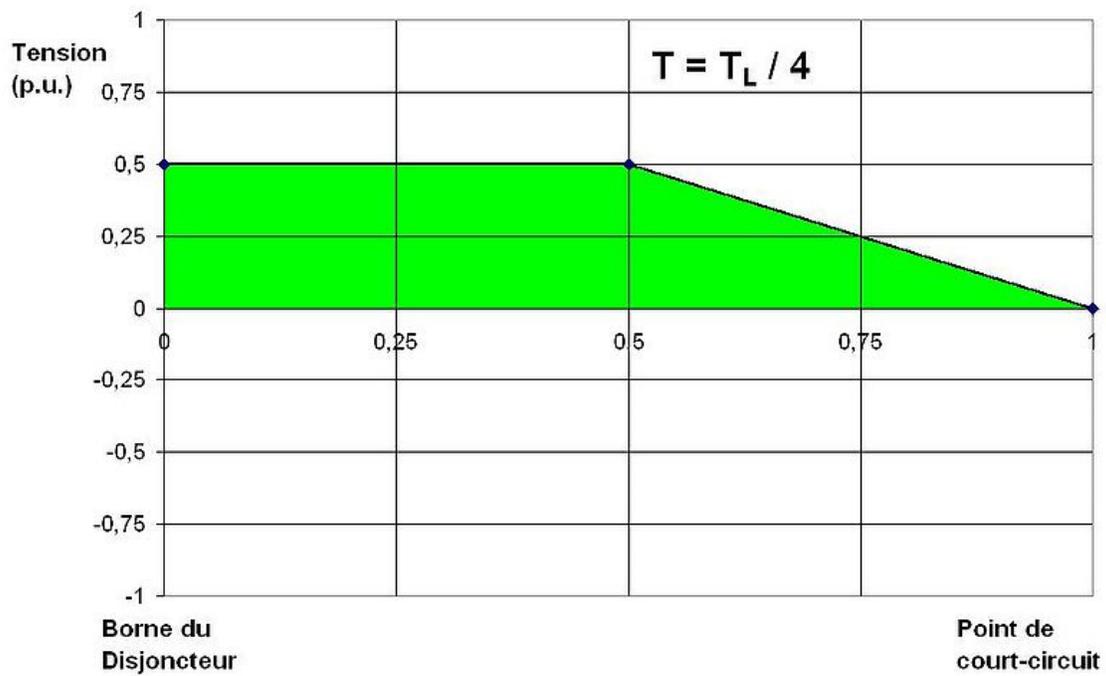


Figure 8 - Instant  $T_L/4$

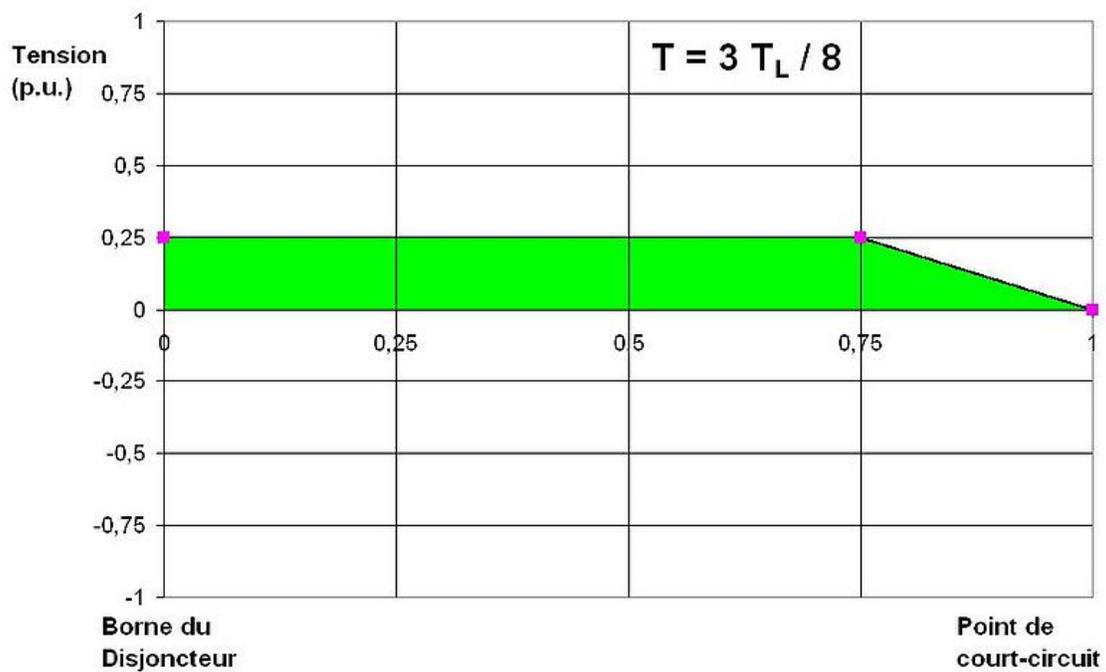


Figure 9 - Instant  $3T_L/8$

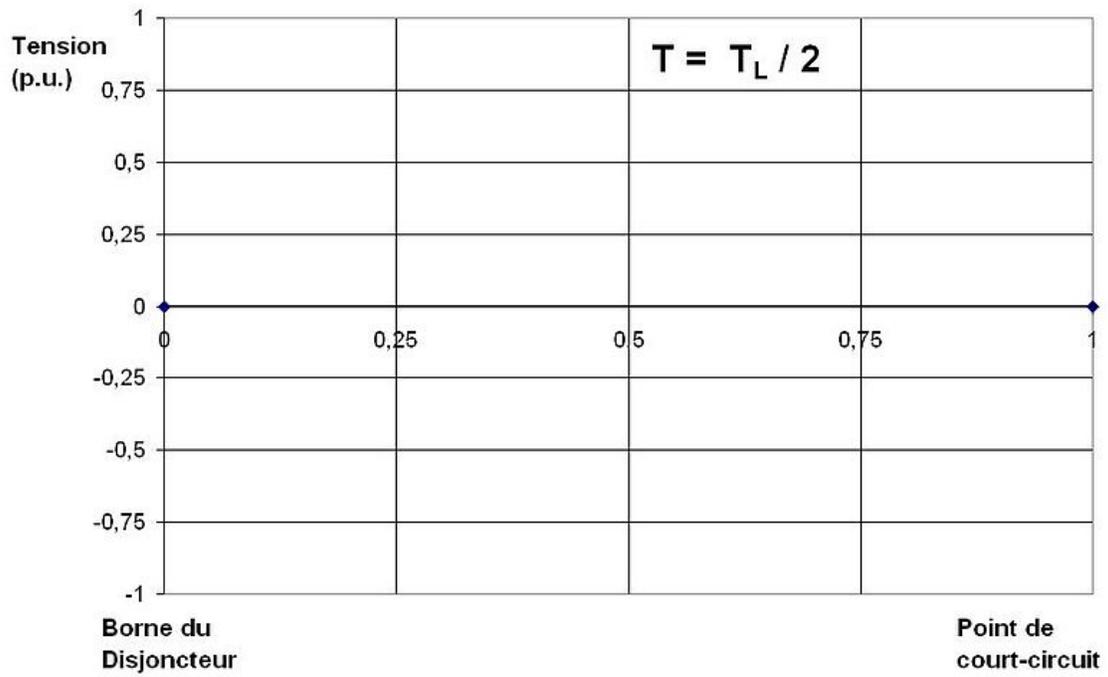


Figure 10 - Instant  $T_L/2$

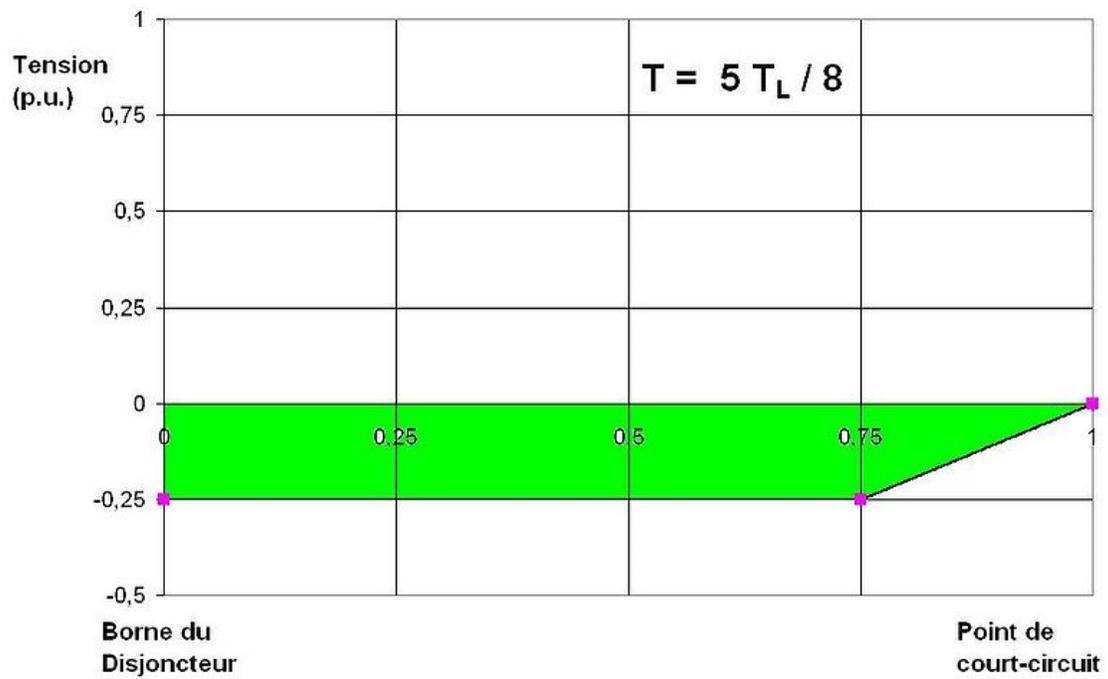


Figure 11 - Instant  $5T_L/8$

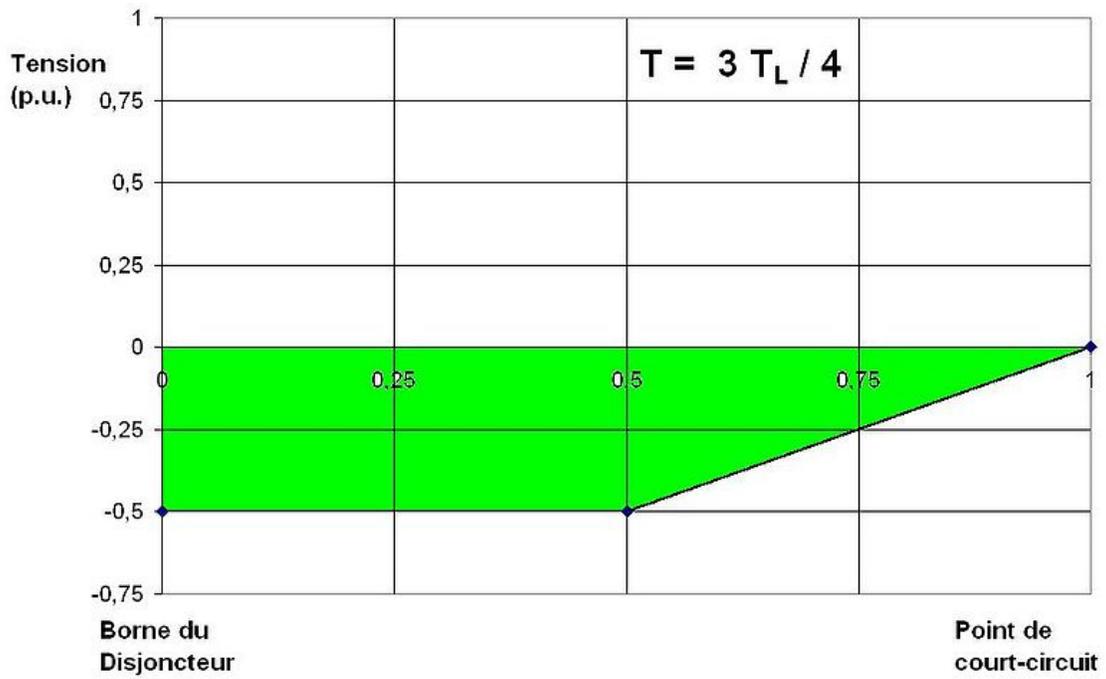


Figure 12 - Instant  $3T_L/4$

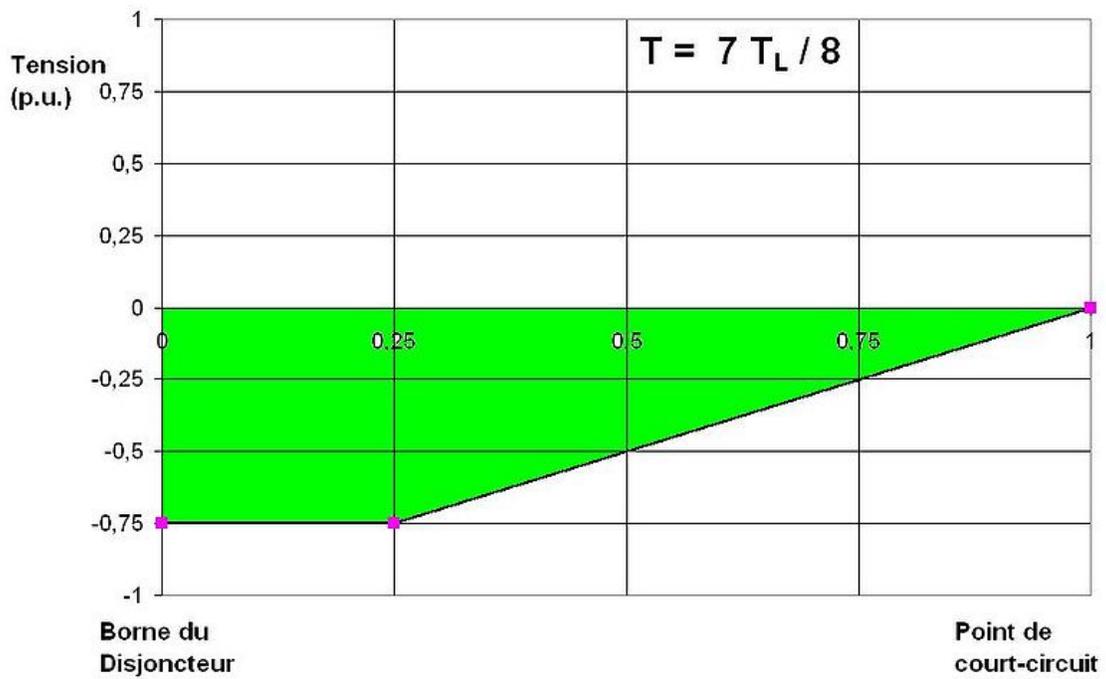


Figure 13 - Instant  $7T_L/8$

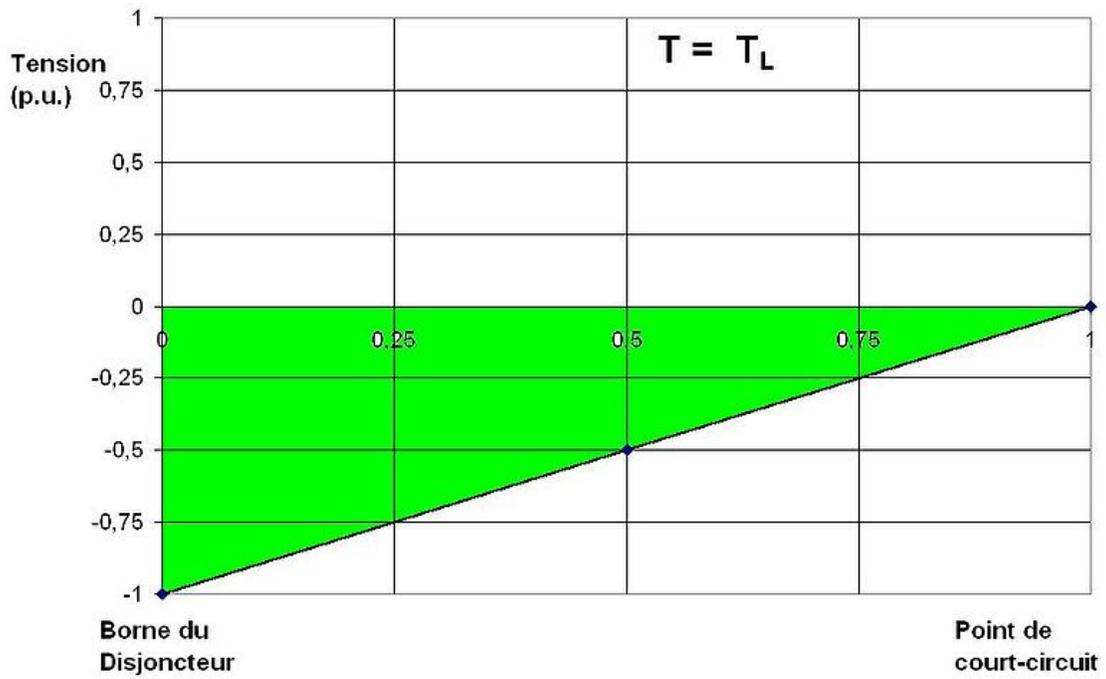


Figure 14 - Instant  $T_L$

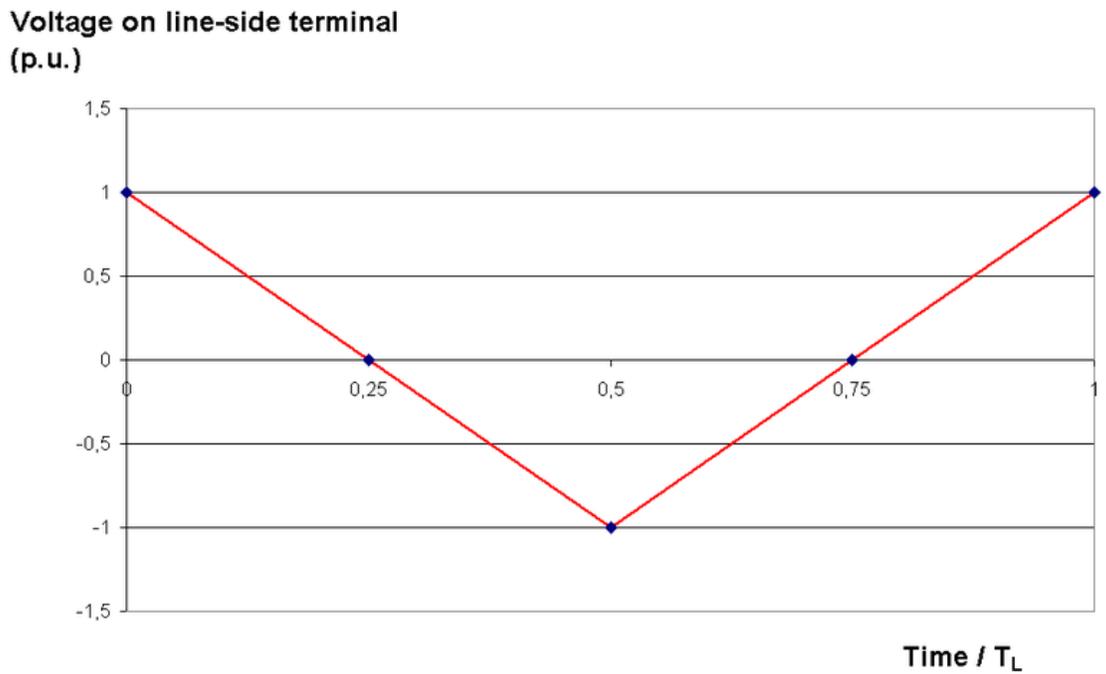


Figure 15 - Time-variation of voltage on the line-side terminal of the circuit breaker

A short-line-fault TRV is characterized by a rate-of-rise that is proportional to the slope of current at the time of interruption and therefore to the amplitude of the short-circuit

current :  $\frac{du}{dt} = Z \frac{di}{dt}$ , where  $Z$  is the surge impedance of the line.

The standardized value of  $Z$  is  $450 \Omega$ , it is equal to  $\sqrt{l/c}$ , where  $l$  and  $c$  are the line self inductance and capacitance per unit length.

### Out-of-phase condition

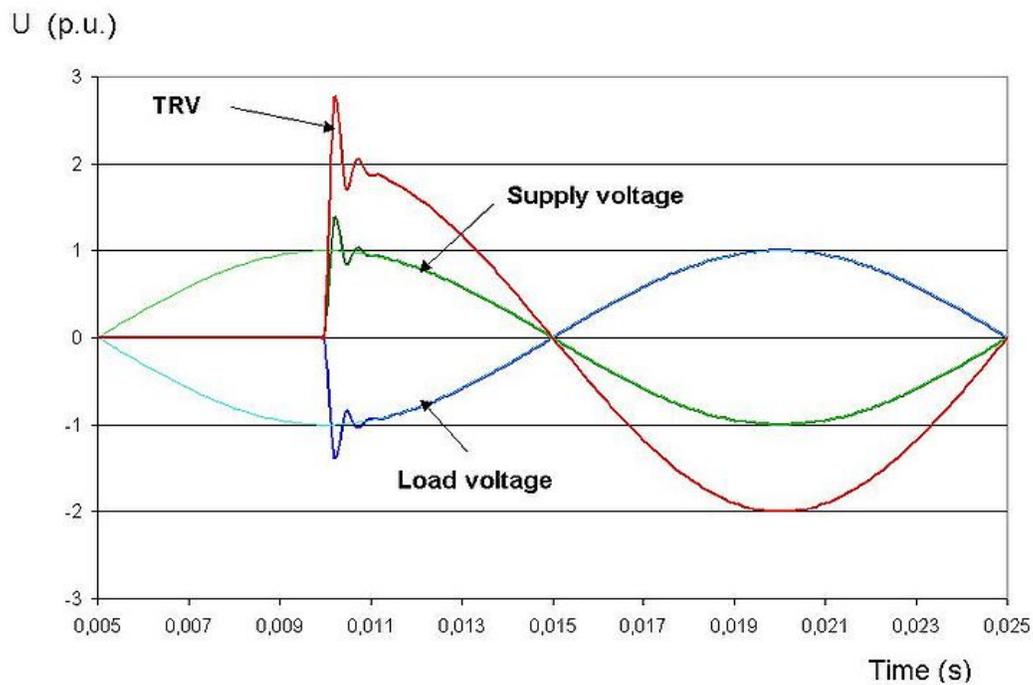


Figure 17 - TRV in out-of-phase conditions

# 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)**

<b>Region or Country</b>	<b>Phases</b>	<b>Neutral</b>	<b>Protective earth/ground</b>
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)**

<b>Region or Country</b>	<b>Phases</b>	<b>Neutral</b>	<b>Protective earth/ground</b>
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)	white (120/208/240V)	green ( <i>green</i> )

	<i>(brass)</i> brown, orange, yellow (277/480V)	<i>(silver)</i> grey(277/480V)	bare conductor green/yellow (isolated ground)
Canada	red, black (120/208/240V) red, black, blue (600/347V)	white (120/208/240V) white (600/347V)	green <i>(green)</i> 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 16mm<sup>2</sup> (5AWG) with PVC insulation

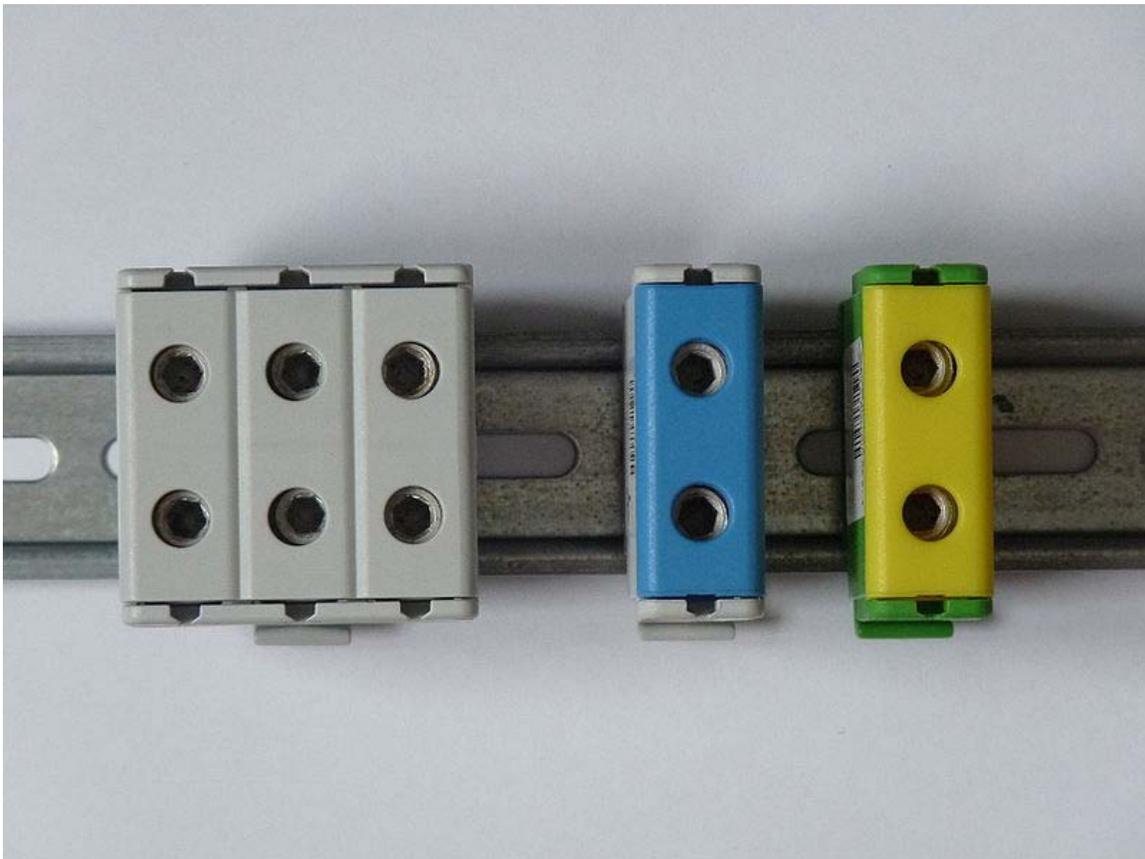
About 1950, PVC insulation and jackets were introduced, especially for residential wiring. About the same time, single conductors with a thinner PVC insulation and a thin nylon jacket became common.

The simplest form of cable has two insulated conductors twisted together to form a unit; such unjacketed cables with two or three conductors are used for low-voltage signal and control applications such as doorbell wiring. In North American practice, an overhead cable from a transformer on a power pole to a residential electrical service consists of

three twisted (triplexed) wires, often with one being a bare copper wire (protective earth/ground) and the other two being insulated for the line voltage (hot/live wire and neutral wire).

## **Aluminium conductors**

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



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

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

to cold-flow under pressure, so screw clamped connections may get loose over time. This can be mitigated by using spring-loaded connectors that apply constant pressure, applying high pressure cold joints in splices and termination fittings, and torquing the bolted connection. Unlike copper, aluminium forms an insulating oxide layer on the surface. This is sometimes addressed by coating aluminium wires with an antioxidant paste at joints, or applying a mechanical termination designed to break through the oxide layer during installation.

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

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

## Modern wiring materials



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

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

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

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

Generally, single conductor building wire in small sizes is solid wire, since the wiring is not required to be very flexible. Building wire conductors larger than 10 AWG (or about 6 mm<sup>2</sup>) 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.

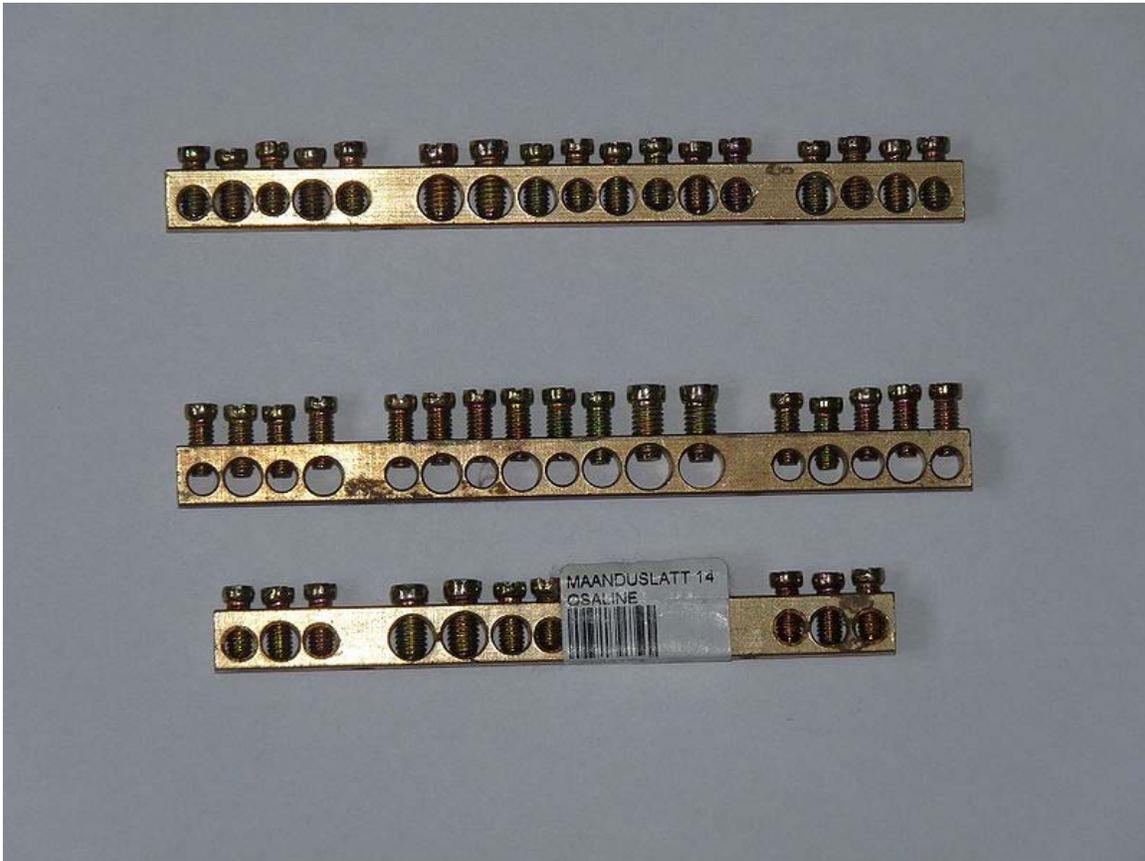
## ***Bus bars, bus duct, cable bus***



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*



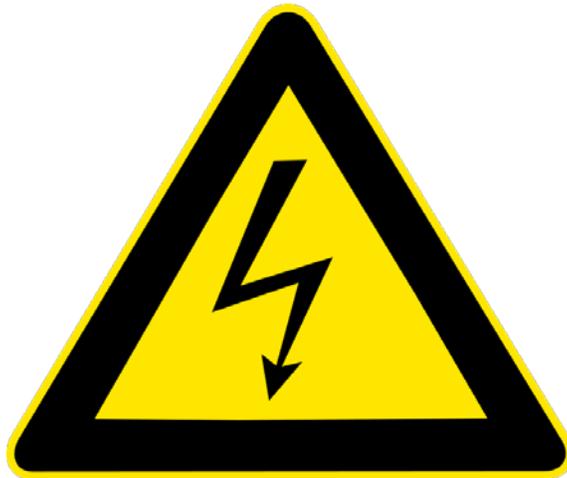
Electrical panels in an electrical service room at St. Mary's Pulp and Paper, Sault Ste. Marie, Ontario, Canada, April 1996

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 5

# Voltage



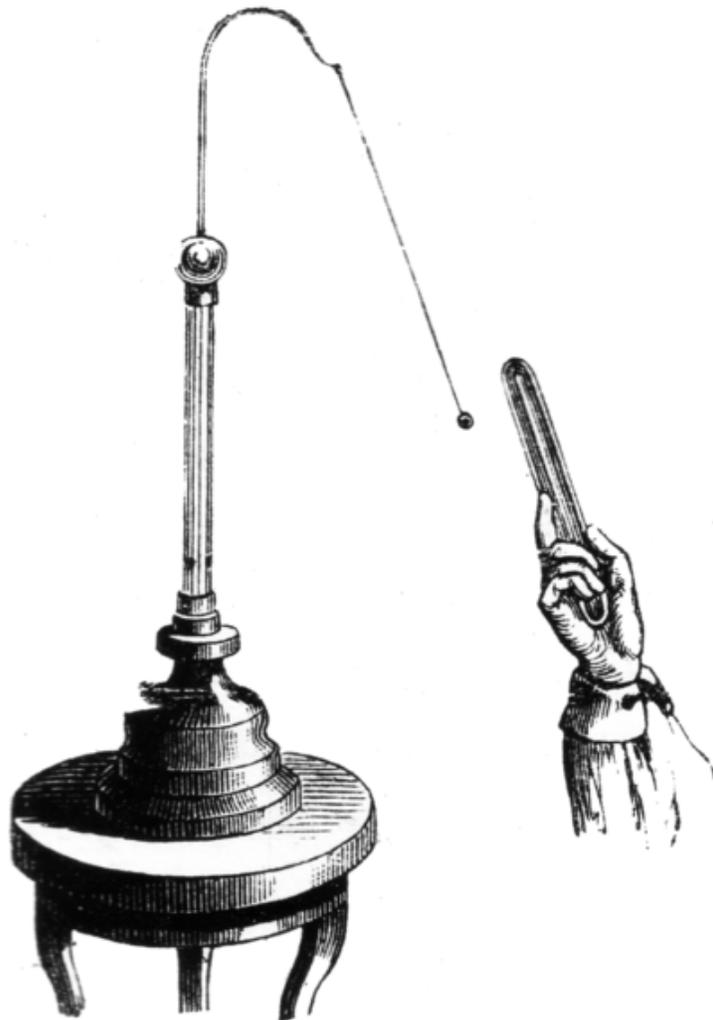
International safety symbol "Caution, risk of electric shock" (ISO 3864), colloquially known as **High voltage**.

The **voltage** between two points is a short name for the electrical driving force (the concept of driving force is not a force measured in newtons) that could determine an electric current between those points. It is used interchangeably with electric potential difference and electric tension. Specifically, voltage is equal to energy per unit charge. In the case of static electric fields, the voltage between two points is equal to the **electrical potential difference** between those points. In the more general case with electric and magnetic fields that vary with time, the terms are no longer synonymous.

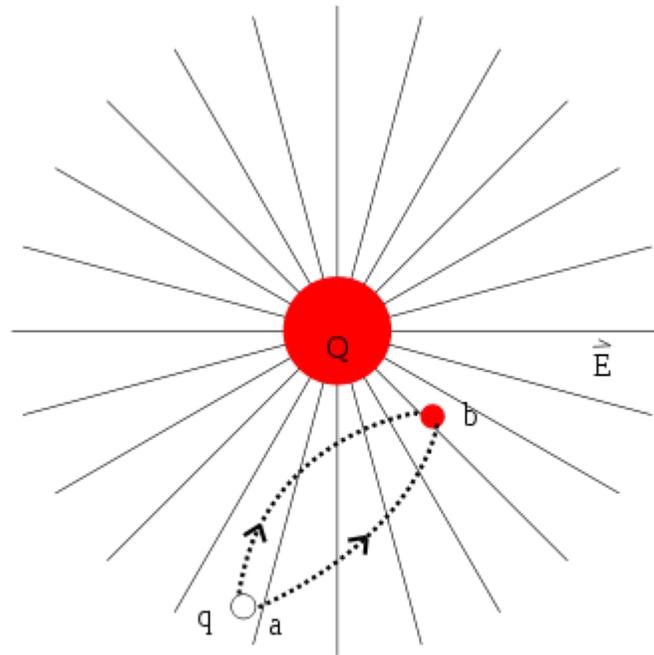
Electric potential is the energy required to move a unit of electric charge to a particular place in a static electric field.

Voltage can be measured by a voltmeter. The unit of measurement is the volt.

***Definition***



The electric field around the rod exerts a force on the charged pith ball, in an electrostatic.



In a static field, the work is independent of the path.

The voltage between two ends of a path is the total energy required to move a small electric charge along that path, divided by the magnitude of the charge. Mathematically this is expressed as the line integral of the electric field and the time rate of change of magnetic field along that path. In the general case, both a static (unchanging) electric field and a dynamic (time-varying) electromagnetic field must be included in determining the voltage between two points.

Historically this quantity has also been called "tension" and "pressure". Pressure is now obsolete but tension is still used, for example within the phrase "high tension" (HT) which is commonly used in thermionic valve (vacuum tube) based electronics.

Voltage is defined so that electrons and other negatively-charged objects are pulled towards higher voltages, while positively-charged objects are pulled towards lower voltages. Therefore, the conventional current in a wire or resistor always flows from higher voltage to lower voltage. Current can flow from lower voltage to higher voltage, but only when a source of energy is present to "push" it against the opposing electric field. For example, inside a battery, chemical reactions inside the battery provide the energy needed for current to flow from the negative terminal to the positive terminal.

### ***Hydraulic analogy***

A simple analogy for an electric circuit is water flowing in a closed circuit of pipework, driven by a mechanical pump. This can be called a *water circuit*. Potential difference between two points corresponds to the water pressure difference between two points. If there is a water pressure difference between two points, then water flow (due to the pump) from the first point to the second will be able to do work, such as driving a turbine. In a similar way, work can be done by the electric current driven by the potential difference due to an electric battery: for example, the current generated by an automobile battery can drive the starter motor in an automobile. If the pump isn't working, it produces no pressure difference, and the turbine will not rotate. Equally, if the automobile's battery is flat, then it will not turn the starter motor.

This *water flow analogy* is a useful way of understanding several electrical concepts. In such a system, the work done to move water is equal to the pressure multiplied by the volume of water moved. Similarly, in an electrical circuit, the work done to move electrons or other charge-carriers is equal to "electrical pressure" (an old term for voltage) multiplied by the quantity of electrical charge moved. Voltage is a convenient way of measuring the ability to do work. In relation to "flow", the larger the "pressure difference" between two points (potential difference or water pressure difference) the greater the flow between them (either electric current or water flow).

### ***Applications***

Specifying a voltage measurement requires explicit or implicit specification of the points across which the voltage is measured. When using a voltmeter to measure potential difference, one electrical lead of the voltmeter must be connected to the first point, one to the second point.

A common use of the term "voltage" is in describing the voltage dropped across an electrical device (such as a resistor). The voltage drop across the device can be understood as the difference between measurements at each terminal of the device with respect to a common reference point (or ground). The voltage drop is the difference between the two readings. Two points in an electric circuit that are connected by an ideal conductor without resistance and not within a changing magnetic field, have a voltage of zero. Any two points with the same potential may be connected by a conductor and no current will flow between them.

## Addition of voltages

The voltage between  $A$  and  $C$  is the sum of the voltage between  $A$  and  $B$  and the voltage between  $B$  and  $C$ . The various voltages in a circuit can be computed using Kirchhoff's circuit laws.

When talking about alternating current (AC) there is a difference between instantaneous voltage and average voltage. Instantaneous voltages can be added for direct current (DC) and AC, but average voltages can be meaningfully added only when they apply to signals that all have the same frequency and phase.

## Measuring instruments

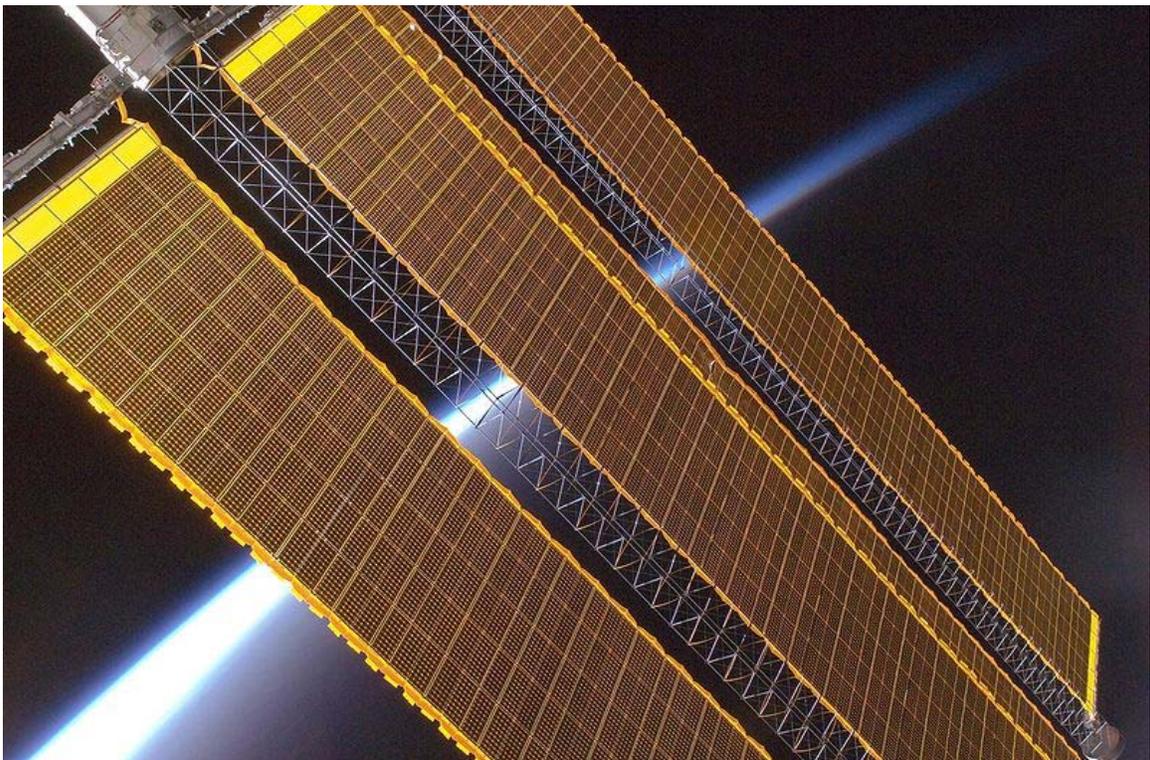


A multimeter set to measure voltage.

Instruments for measuring voltages include the voltmeter, the potentiometer, and the oscilloscope. The voltmeter works by measuring the current through a fixed resistor, which, according to Ohm's Law, is proportional to the voltage across the resistor. The potentiometer works by balancing the unknown voltage against a known voltage in a bridge circuit. The cathode-ray oscilloscope works by amplifying the voltage and using it to deflect an electron beam from a straight path, so that the deflection of the beam is proportional to the voltage.

## Chapter 6

# Electrical System of the International Space Station



International Space Station solar array wing (Expedition 17 crew, August 2008).

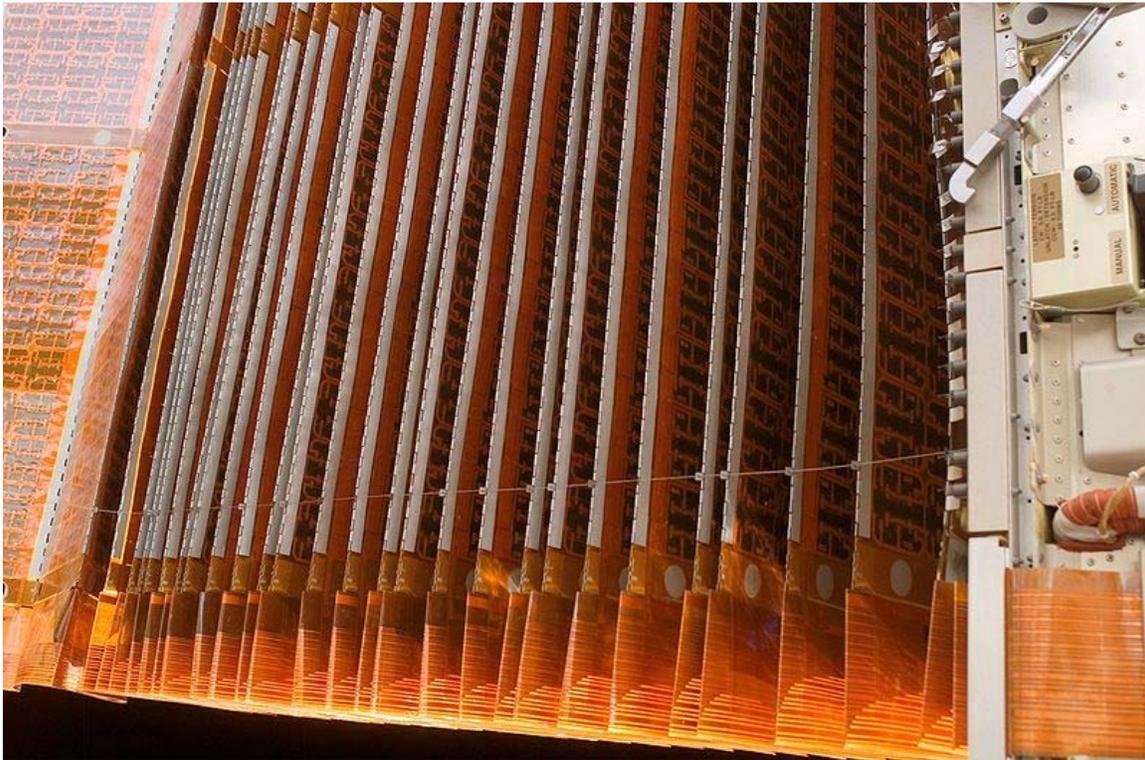


An ISS solar panel intersecting Earth's horizon.

The **electrical system of the International Space Station** is a critical resource for the International Space Station (ISS) because it allows the crew to live comfortably, to safely operate the station, and to perform scientific experiments. The ISS electrical system uses solar cells to directly convert sunlight to electricity. Large numbers of cells are assembled in arrays to produce high power levels. This method of harnessing solar power is called photovoltaics.

The process of collecting sunlight, converting it to electricity, and managing and distributing this electricity builds up excess heat that can damage spacecraft equipment. This heat must be eliminated for reliable operation of the space station in orbit. The ISS power system uses radiators to dissipate the heat away from the spacecraft. The radiators are shaded from sunlight and aligned toward the cold void of deep space.

## **Solar array wing**



Close-up view of folded solar array.

Each ISS solar array wing (often abbreviated "SAW") consists of two retractable "blankets" of solar cells with a mast between them. Each wing uses nearly 33,000 solar cells and when fully extended is 35 m (115 ft) long and 12 m (38 ft) wide. When retracted, each wing folds into a solar array blanket box just 51 cm (20 inches) high and 4.57 m (15 ft) long. The ISS now has the full complement of eight solar array wings.

The solar arrays normally track the Sun, with the "alpha gimbal" used as the primary rotation to follow the Sun as the space station moves around the Earth, and the "beta gimbal" used to adjust for the angle of the space station's orbit to the ecliptic. Several different tracking modes are used in operations, ranging from full Sun-tracking, to the drag-reduction mode ("Night glider" and "Sun slicer" modes), to a drag-maximization mode used to lower the altitude.

## **Batteries**

Since the station is often not in direct sunlight, it relies on rechargeable nickel-hydrogen batteries to provide continuous power during the "eclipse" part of the orbit (35 minutes of every 90 minute orbit). The batteries ensure that the station is never without power to sustain life-support systems and experiments. During the sunlit part of the orbit, the batteries are recharged. The batteries have a working life of 6.5 years which means that

they must be replaced multiple times during the expected 20-year life of the station. The batteries, and the battery charge/discharge units (BCDUs), are manufactured by Space Systems/Loral (SS/L), under contract to Boeing.

### ***Power management and distribution***

The power management and distribution subsystem operates at a primary bus voltage set to  $V_{mp}$ , the peak power point of the solar arrays. As of December 30, 2005,  $V_{mp}$  was 160 volts DC (direct current). It can change over time as the arrays degrade from ionizing radiation. Microprocessor-controlled switches control the distribution of primary power throughout the station.

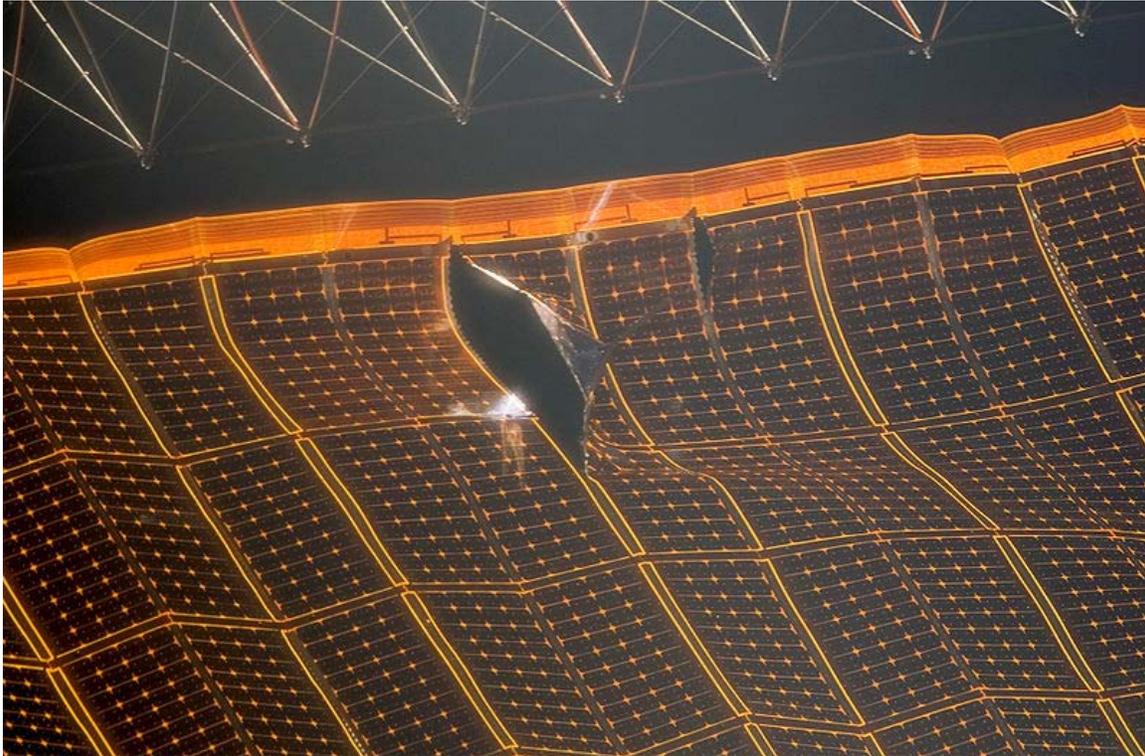
### **SSU**

Eighty-two separate solar array strings feed a sequential shunt unit (SSU) that provides coarse voltage regulation at the desired  $V_{mp}$ . The SSU applies a "dummy" (resistive) load that increases as the station's load decreases (and vice versa) so the array operates at a constant voltage and load. The SSUs are provided by SS/L.

### **DC-to-DC conversion**

DC-to-DC converter units supply the secondary power system at a constant 124.5 volts DC, allowing the primary bus voltage to track the peak power point of the solar arrays.

## ***Station to shuttle power transfer system***



Damage to the 4B wing of the P6 solar array wing found when it was redeployed after being moved to its final position on the STS-120 mission.

The Station-to-Shuttle Power Transfer System (SSPTS) allows a docked Space Shuttle to make use of power provided by the International Space Station's solar arrays. Using this system reduces usage of a shuttle's on-board power-generating fuel cells, allowing it to stay docked to the space station for an additional four days.

SSPTS is a shuttle upgrade that replaces the Assembly Power Converter Unit (APCU) with a new device called the Power Transfer Unit (PTU). The APCU had the capacity to convert shuttle 28 VDC main bus power to 124 VDC compatible with ISS's 120 VDC power system. This was used in the initial construction of the space station to augment the power available from the Russian *Zvezda* service module. The PTU adds to this the capability to convert the 120 VDC supplied by the ISS to the orbiter's 28 VDC main bus power. It is capable of transferring up to eight kilowatts of power from the space station to the orbiter. With this upgrade both the shuttle and the ISS are now able to use each other's power systems when needed, although it is not expected that the ISS will ever again require the use of an orbiter's power systems.

During mission STS-116, PMA-2 (at the forward end of the *Harmony* module) was rewired to allow for the use of the SSPTS. The first mission to make actual use of the system was STS-118 with Space Shuttle *Endeavour*.

Currently only *Discovery* and *Endeavour* are equipped with the SSPTS. As of May 2010, *Atlantis* is not equipped with the SSPTS.

## Chapter 7

# Burglar Alarm



A photo-infrared motion sensor of a burglar alarm detection point

**Burglar (or intrusion), fire, and safety alarms** are electronic alarms designed to alert the user to a specific danger. Sensors are connected to a control unit via low-voltage wiring or a narrowband RF signal which is used to interact with a response device. The most common security sensors are used to indicate the opening of a door or window or detect motion via passive infrared (PIR). New construction systems are predominately hardwired for economy. Retrofit installations often use wireless systems for a faster, more economical installation. Some systems serve a single purpose of burglar or fire protection. Combination systems provide both fire and intrusion protection. Systems range from small, self-contained noisemakers, to complicated, multi-zoned systems with

color-coded computer monitor outputs. Many of these concepts also apply to portable alarms for protecting cars, trucks or other vehicles and their contents (i.e., "car alarms").

Burglar alarms (or **perimeter security systems**, **perimeter detection systems**, **Perimeter protection**, **intrusion detection systems** and many more terms for the same thing) are divided to two main fields: home burglar alarms and industrial burglar and perimeter intrusion detection.

## ***Alarm types***

### **Indoor**

These types of sensors are designed for indoor use. Outdoor use would not be advised due to false alarm vulnerability and weather durability.

### **Passive infrared detectors**

The passive infrared detector (PIR) is one of the most common detectors found in household and small business environments because it offers affordable and reliable functionality. The term *passive* means the detector is able to function without the need to generate and radiate its own energy (unlike ultrasonic and microwave volumetric intrusion detectors that are "active" in operation). PIRs are able to distinguish if an infrared emitting object is present by first learning the ambient temperature of the monitored space and then detecting a change in the temperature caused by the presence of an object. Using the principle of differentiation, which is a check of presence or nonpresence, PIRs verify if an intruder or object is actually there. Creating individual zones of detection where each zone comprises one or more layers can achieve differentiation. Between the zones there are areas of no sensitivity (dead zones) that are used by the sensor for comparison.

### **Ultrasonic detectors**

Using frequencies between 15 kHz and 75 kHz, these active detectors transmit ultrasonic sound waves that are inaudible to humans. The Doppler shift principle is the underlying method of operation, in which a change in frequency is detected due to object motion. This is caused when a moving object changes the frequency of sound waves around it. Two conditions must occur to successfully detect a Doppler shift event:

- There must be motion of an object either towards or away from the receiver.
- The motion of the object must cause a change in the ultrasonic frequency to the receiver relative to the transmitting frequency.

The ultrasonic detector operates by the transmitter emitting an ultrasonic signal into the area to be protected. The sound waves are reflected by solid objects (such as the surrounding floor, walls and ceiling) and then detected by the receiver. Because

ultrasonic waves are transmitted through air, then hard-surfaced objects tend to reflect most of the ultrasonic energy, while soft surfaces tend to absorb most energy.

When the surfaces are stationary, the frequency of the waves detected by the receiver will be equal to the transmitted frequency. However, a change in frequency will occur as a result of the Doppler principle, when a person or object is moving towards or away from the detector. Such an event initiates an alarm signal. This technology is considered obsolete by many alarm professionals, and is not actively installed.

## **Microwave detectors**

This device emits microwaves from a transmitter and detects any reflected microwaves or reduction in beam intensity using a receiver. The transmitter and receiver are usually combined inside a single housing (monostatic) for indoor applications, and separate housings (bistatic) for outdoor applications. To reduce false alarms this type of detector is usually combined with a passive infrared detector or "Dualtec" alarm.

By generating energy in the microwave region of the electromagnetic spectrum, detector operates as an active volumetric device that responds to:

- A Doppler shift frequency change.
- A frequency phase shift.
- A motion causing reduction in received energy.

## **Photo-electric beams**

Photoelectric beam systems detect the presence of an intruder by transmitting visible or infrared light beams across an area, where these beams may be obstructed. To improve the detection surface area, the beams are often employed in stacks of two or more. However, if an intruder is aware of the technology's presence, it can be avoided. The technology can be an effective long-range detection system, if installed in stacks of three or more where the transmitters and receivers are staggered to create a fence-like barrier. Systems are available for both internal and external applications. To prevent a clandestine attack using a secondary light source being used to hold the detector in a 'sealed' condition whilst an intruder passes through, most systems use and detect a modulated light source.

## **Glass break detectors**

The glass break detector may be used for internal perimeter building protection. When glass breaks it generates sound in a wide band of frequencies. These can range from infrasonic, which is below 20 hertz (Hz) and can not be heard by the human ear, through the audio band from 20 Hz to 20 kHz which humans can hear, right up to ultrasonic, which is above 20 kHz and again cannot be heard. Glass break acoustic detectors are mounted in close proximity to the glass panes and listen for sound frequencies associated with glass breaking. Seismic glass break detectors are different in that they are installed on the glass pane. When glass breaks it produces specific shock frequencies which travel

through the glass and often through the window frame and the surrounding walls and ceiling. Typically, the most intense frequencies generated are between 3 and 5 kHz, depending on the type of glass and the presence of a plastic interlayer. Seismic glass break detectors “feel” these shock frequencies and in turn generate an alarm condition.

The more primitive detection method involves gluing a thin strip of conducting foil on the inside of the glass and putting low-power electrical current through it. Breaking the glass is practically guaranteed to tear the foil and break the circuit.

### **Smoke, heat, and carbon monoxide detectors**

Most systems may also be equipped with smoke, heat, and/or carbon monoxide detectors. These are also known as 24 hour zones (which are on at all times). Smoke detectors and heat detectors protect from the risk of fire and carbon monoxide detectors protect from the risk of carbon monoxide.

### ***Outdoor***

These types of sensors would be found most of the time mounted on fences or installed on the perimeter of the protected area.

### **Vibration (shaker) or inertia sensors**

These devices are mounted on barriers and are used primarily to detect an attack on the structure itself. The technology relies on an unstable mechanical configuration that forms part of the electrical circuit. When movement or vibration occurs, the unstable portion of the circuit moves and breaks the current flow, which produces an alarm. The technology of the devices varies and can be sensitive to different levels of vibration. The medium transmitting the vibration must be correctly selected for the specific sensor as they are best suited to different types of structures and configurations.

A rather new and unproven type of sensors use piezo-electric components rather than mechanical circuits, which can be tuned to be extremely sensitive to vibration.

- pros: Very reliable sensors, low false alarm rate and middle place in the price range.
- cons: Must be fence mounted. The rather high price deters many customers, but its effectiveness offsets its high price. Piezo-electric sensors are a new technology with an unproven record as opposed to the mechanical sensor which in some cases has a field record in excess of 20 years.

### **Passive magnetic field detection**

This buried security system is based on the Magnetic Anomaly Detection principle of operation. The system uses an electromagnetic field generator powered by two wires running in parallel. Both wires run along the perimeter and are usually installed about

5 inches apart on top of a wall or about 12"/30 cm below ground. The wires are connected to a signal processor which analyzes any change in the magnetic field.

This kind of buried security system sensor cable could be buried on the top of almost any kind of wall to provide a regular wall detection ability or be buried in the ground.

- pros: Very low false alarm rate, can be put on top of any wall, very high chance of detecting real burglars.
- cons: Cannot be installed near high voltage lines, radars.

## **E-field**

This proximity system can be installed on building perimeters, fences, and walls. It also has the ability to be installed free standing on dedicated poles. The system uses an electromagnetic field generator powering one wire, with another sensing wire running parallel to it. Both wires run along the perimeter and are usually installed about 800 millimetres apart. The sensing wire is connected to a signal processor that analyses:

- amplitude change (mass of intruder),
- rate change (movement of intruder),
- preset disturbance time (time the intruder is in the pattern).

These items define the characteristics of an intruder and when all three are detected simultaneously, an alarm signal is generated.

The barrier can provide protection from the ground to about 4 metres of altitude. It is usually configured in zones of about 200 metre lengths depending on the number of sensor wires installed.

- pros: concealed as a buried form.
- cons: expensive, short zones which mean more electronics (more money), high rate of false alarms as it cannot distinguish a cat from a human. In reality it does not work that well, as extreme weather causes false alarms.

## **Microwave barriers**

The operation of a microwave barrier is very simple. This type of device produces an electromagnetic beam using high frequency waves that pass from the transmitter to the receiver, creating an invisible but sensitive wall of protection. When the receiver detects a difference of condition within the beam (and hence a possible intrusion), the system begins a detailed analysis of the situation. If the system considers the signal a real intrusion, it provides an alarm signal that can be treated in analog or digital form.

- pros: low cost, easy to install, invisible perimeter barrier, unknown perimeter limits to the intruder.

- cons: extremely sensitive to weather as rain, snow and fog for example would cause the sensors to stop working, need sterile perimeter line because trees, bushes or anything that blocks the beam would cause false alarm or lack of detection.

## **Microphonic systems**

Microphonic based systems vary in design but each is generally based on the detection of an intruder attempting to cut or climb over a chainwire fence. Usually the microphonic detection systems are installed as sensor cables attached to rigid chainwire fences, however some specialised versions of these systems can also be installed as buried systems underground. Depending on the version selected, it can be sensitive to different levels of noise or vibration. The system is based on coaxial or electro-magnetic sensor cable with the controller having the ability to differentiate between signals from the cable or chainwire being cut, an intruder climbing the fence, or bad weather conditions.

The systems are designed to detect and analyse incoming electronic signals received from the sensor cable, and then to generate alarms from signals which exceed preset conditions. The systems have adjustable electronics to permit installers to change the sensitivity of the alarm detectors to the suit specific environmental conditions. The tuning of the system is usually accomplished during commissioning of the detection devices.

- pros: very cheap, very simple configuration, easy to install.
- cons: some systems has a high rate of false alarms because some of these sensors might be too sensitive. Although systems using DSP (Digital Signal Processing) will largely eliminate false alarms on some cases.

## **Taut wire fence systems**

A taut wire perimeter security system is basically an independent screen of tensioned tripwires usually mounted on a fence or wall. Alternatively, the screen can be made so thick that there is no need for a supporting chainwire fence. These systems are designed to detect any physical attempt to penetrate the barrier. Taut wire systems can operate with a variety of switches or detectors that sense movement at each end of the tensioned wires. These switches or detectors can be a simple mechanical contact, static force transducer or an electronic strain gauge. Unwanted alarms caused by animals and birds can be avoided by adjusting the sensors to ignore objects that exert small amounts of pressure on the wires. This type of system is vulnerable to intruders digging under the fence. A concrete footing directly below the fence is installed to prevent this type of attack.

- pros: low rate of false alarms, very reliable sensors and high rate of detection.
- cons: Very expensive, complicated to install and old technology.

## **Fibre optic cable**

A fibre-optic cable can be used to detect intruders by measuring the difference in the amount of light sent through the fibre core. If the cable is disturbed, light will 'leak' out and the receiver unit will detect a difference in the amount of light received. The cable can be attached directly to a chainwire fence or bonded into a barbed steel tape that is used to protect the tops of walls and fences. This type of barbed tape provides a good physical deterrent as well as giving an immediate alarm if the tape is cut or severely distorted. Other types work on the detection of change in polarization which is caused by fiber position change.

- pros: very similar to the Microphonic system, very simple configuration, easy to install.
- cons: high rate of false alarm or no alarms at all for systems using light that leaks out of the optical fiber. The polarization changing system is much more sensitive but false alarms depend on the alarm processing.

## **H-field**

This system employs an electro-magnetic field disturbance principle based on two unshielded (or 'leaky') coaxial cables buried about 10–15 cm deep and located at about 1 metre apart. The transmitter emits continuous Radio Frequency (RF) energy along one cable and the energy is received by the other cable. When the change in field strength weakens due to the presence of an object and reaches a pre-set lower threshold, an alarm condition is generated. The system is unobtrusive when it has been installed correctly, however care must be taken to ensure the surrounding soil offers good drainage in order to reduce nuisance alarms.

- pros: concealed as a buried form.
- cons: can be affected by RF noise, high rate of false alarms, hard to install.

## ***System connections***

The trigger signal from each sensor is transmitted to one or more control unit(s) either through wires or wireless means (radio, line carrier, infrared). Wired systems are convenient when sensors (such as PIRs, smoke detectors etc.) require power to operate correctly, however, they may be more costly to install. Entry-level wired systems utilize a Star network topology, where the panel is at the center logically, and all devices "home run" its wire back to the panel. More complex panels use a Bus network topology where the wire basically is a data loop around the perimeter of the facility, and has "drops" for the sensor devices which must include a unique device identifier integrated into the sensor device itself (e.g. iD biscuit). Wired systems also have the advantage, if wired properly, of being tamper-evident. Wireless systems, on the other hand, often use battery-powered transmitters which are easier to install, but may reduce the reliability of the system if the sensors are not supervised, or if the batteries are not maintained. Depending on distance and construction materials, one or more wireless repeaters may be required to

get the signal reliably back to the alarm panel. Hybrid systems utilize both wired and wireless sensors to achieve the benefits of both. Transmitters, or sensors can also be connected through the premises electrical circuits to transmit coded signals to the control unit (line carrier). The control unit usually has a separate channel or zone for burglar and fire sensors, and better systems have a separate zone for every different sensor, as well as internal "trouble" indicators (mains power loss, low battery, wire broken, etc.).

### ***Alarm connection and monitoring***

Depending upon the application, the alarm output may be local, remote or a combination. Local alarms do not include monitoring, though may include indoor and/or outdoor sounders (e.g. motorized bell or electronic siren) and lights (e.g. strobe light) which may be useful for signaling an evacuation notice for people during fire alarms, or where one hopes to scare off an amateur burglar quickly. However, with the widespread use of alarm systems (especially in cars), false alarms are very frequent and many urbanites tend to ignore alarms rather than investigating, let alone contacting the necessary authorities. In short, there may be no response at all. In rural areas (e.g., where nobody will hear the fire bell or burglar siren) lights or sounds may not make much difference anyway, as the nearest responders could take so long to get there that nothing can be done to avoid losses.

Remote alarm systems are used to connect the control unit to a predetermined monitor of some sort, and they come in many different configurations. High-end systems connect to a central station or responder (e.g. Police/ Fire/ Medical) via a direct phone wire (or tamper-resistant fiber optic cable), and the alarm monitoring includes not only the sensors, but also the communication wire itself. While direct phone circuits are still available in some areas from phone companies, because of their high cost they are becoming uncommon. Direct connections are now most usually seen only in Federal, State, and Local Government buildings, or on a school campus that has a dedicated security, police, fire, or emergency medical department (in the UK communication is only possible to an Alarm Receiving Centre - communication direct to the emergency services is not permitted). More typical systems incorporate a digital telephone dialer unit that will dial a central station (or some other location) via the Public Switched Telephone Network (PSTN) and raise the alarm, either with a synthesized voice or increasingly via an encoded message string that the central station decodes. These may connect to the regular phone system on the system side of the demarcation point, but typically connect on the customer side ahead of all phones within the monitored premises so that the alarm system can seize the line by cutting-off any active calls and call the monitoring company if needed. Encoders can be programmed to indicate which specific sensor was triggered, and monitors can show the physical location (or "zone") of the sensor on a list or even a map of the protected premises, which can make the resulting response more effective. For example, a water-flow alarm, coupled with a flame detector in the same area is a more reliable indication of an actual fire than just one or the other sensor indication by itself. Many alarm panels are equipped with a backup dialer capability for use when the primary PSTN circuit is not functioning. The redundant dialer may be connected to a second phone line, or a specialized encoded cellular phone, radio, or internet interface device to

bypass the PSTN entirely, to thwart intentional tampering with the phone line(s). Just the fact that someone tampered with the line could trigger a supervisory alarm via the radio network, giving early warning of an imminent problem (e.g., arson). In some cases a remote building may not have PSTN phone service, and the cost of trenching and running a direct line may be prohibitive. It is possible to use a wireless cellular or radio device as the primary communication method.

### ***Broadband Alarm Monitoring***

Increasing deployment of voice over IP technology (VoIP) is driving the adoption of broadband signaling for alarm reporting. Many sites requiring alarm installations no longer have conventional telephone lines (POTS), and alarm panels with conventional telephone dialer capability do not work reliably over some types of VoIP service.

Dial up analog alarm panels or systems with serial/parallel data ports may be migrated to broadband through the addition of an alarm server device which converts telephone signaling signals or data port traffic to IP messages suitable for broadband transmission. But the direct use of VoIP (POTS port on premises terminal) to transport analog alarms without an alarm server device is problematic as the audio codecs used throughout the entire network transmission path cannot guarantee a suitable level of reliability or quality of service acceptable for the application.

In response to the changing public communications network, new alarm systems often can use broadband signaling as a method of alarm transmission, and manufacturers are including IP reporting capability directly in their alarm panel products. When the Internet is used as a primary signaling method for critical security and life safety applications, frequent supervision messages are configured to overcome concerns about backup power for network equipment and signal delivery time. But for typical applications, connectivity concerns are controlled by normal supervision messages, sent daily or weekly.

Various IP Alarm transmission protocols exist but most in use today are proprietary. Just as the formats used for conventional telephone reporting were standardized and published, broadband signaling for alarm reporting is being standardized today. In 2007, US alarm manufacturers developed an open standard called DC-09. This standard has been accepted as an American National Standard, and is published as ANSI/SIA DC-09-2007. The protocol provides an encoding scheme and transport mechanism to carry data from 17 previously defined alarm protocols, including the latest Contact ID, SIA DC-03 and SIA 2000 protocols. Several manufacturers of panels and receivers are reported to be developing or have released support for DC-09.

### ***Listen In Alarm monitoring***

Monitored alarms and speaker phones allow for the central station to speak with the homeowner and/or intruder. This may be beneficial to the owner for medical emergencies. For actual break-ins, the speaker phones allow the central station to urge the intruder to cease and desist as response units have been dispatched.

## ***Alarm monitoring Services***

The list of services to be monitored at a Central Station has expanded over the past few years to include: Access Control; CCTV Monitoring; Environmental Monitoring; Intrusion Alarm Monitoring; Fire Alarm & Sprinkler Monitoring; Critical Condition Monitoring; Medical Response Monitoring; Elevator Telephone Monitoring; Hold-Up or Panic Alarm Monitoring; Duress Monitoring; Auto Dialer tests; Open & Close Signal Supervision & Reporting; Exception Reports; and PIN or Passcode Management. Increasingly, the Central Stations are making this information available directly to end users via the internet and a secure log-on to view and create custom reports on these events themselves.

## ***Alarm response***

Depending upon the zone triggered, number and sequence of zones, time of day, and other factors, the monitoring center can automatically initiate various actions. They might be instructed to call the ambulance, fire department or police department immediately, or to first call the protected premises or property manager to try to determine if the alarm is genuine. They could also start calling a list of phone numbers provided by the customer to contact someone to go check on the protected premises. Some zones may trigger a call to the local heating oil company to go check on the system, or a call to the owner with details of which room may be getting flooded. Some alarm systems are tied to video surveillance systems so that current video of the intrusion area can be instantly displayed on a remote monitor, not to mention recorded.

The first video home security system was patented on December 2, 1969 to inventor Marie Brown. The system used television surveillance.

## ***Access control and bypass codes***

To be useful, an intrusion alarm system is deactivated or reconfigured when authorized personnel are present. Authorization may be indicated in any number of ways, often with keys or codes used at the control panel or a remote panel near an entry. High-security alarms may require multiple codes, or a fingerprint, badge, hand-geometry, retinal scan, encrypted response generator, and other means that are deemed sufficiently secure for the purpose.

Failed authorizations should result in an alarm or at least a timed lockout to prevent "experimenting" with possible codes. Some systems can be configured to permit deactivation of individual sensors or groups. Others can also be programmed to bypass or ignore individual sensors (once or multiple times) and leave the remainder of the system armed. This feature is useful for permitting a single door to be opened and closed before the alarm is armed, or to permit a person to leave, but not return. High-end systems allow multiple access codes, and may even permit them to be used only once, or on particular days, or only in combination with other users' codes (i.e., escorted). In any case, a remote monitoring center should arrange an oral code to be provided by an authorized person in

case of false alarms, so the monitoring center can be assured that a further alarm response is unnecessary. As with access codes, there can also be a hierarchy of oral codes, say, for furnace repairperson to enter the kitchen and basement sensor areas but not the silver vault in the butler's pantry. There are also systems that permit a duress code to be entered and silence the local alarm, but still trigger the remote alarm to summon the police to a robbery.

Fire sensors can be "isolated", meaning that when triggered, they will not trigger the main alarm network. This is important when smoke and heat is intentionally produced. The owners of buildings can be fined for generating False alarms that waste the time of emergency personnel.

### ***False / no alarms***

System reliability can be a problem when it causes nuisance alarms, false alarms, or fails to alarm when called for; in all cases, the costs are significant. In many jurisdictions, law enforcement fees for multiple false alarms are significant, and even lead to loss of service, while losses due to undeterred crimes can be large or even priceless.

Approximately 1% of police alarm calls actually involve a crime. Nuisance alarms occur when an unintended event evokes an alarm status by an otherwise properly working alarm system. A false alarm also occurs when there is an alarm system malfunction that results in an alarm state. In all three circumstances, the source of the problem should be immediately found and fixed, so that responders will not lose confidence in the alarm reports. It is easier to know when there are false alarms, because the system is designed to react to that condition. Failure alarms are more troublesome because they usually require periodic testing to make sure the sensors are working and that the correct signals are getting through to the monitor. Some systems are designed to detect problems internally, such as low or dead batteries, loose connections, phone circuit trouble, etc. While earlier nuisance alarms could be set off by small disturbances, like insects or pets, newer model alarms have technology to measure the size/weight of the object causing the disturbance, and thus are able to decide how serious the threat is, which is especially useful in burglar alarms.

### ***False-Alarm Reduction***

Home and business owners can now choose a new type of keypad control panel designed to help reduce false alarms.

Based on a standard called CP-01-2000, developed by the American National Standards Institute and Security Industry Association, the new generation of keypad control panels takes aim at user error by building in extra precautions that minimize unwarranted dispatch of emergency responders.

Some of the features of CP-01 keypads include a progress annunciation function that emits a different sound during the last 10 seconds of delay, which hastens exit from the premises. Also, the exit time doubles if the user disables the pre-warning feature.

Other "rules" address failure to exit premises, which results in arming all zones in Stay Mode and a one-time, automatic restart of exit delay. However, if there is an exit error, an immediate local alarm will sound.

### ***Cross zoning reduces alarms***

Cross zoning is an innovative alarm-system strategy that does not require a new keypad. Using multiple sensors to monitor activity in one area, advanced software analyzes input from all the sources.

For example, if a motion detector trips in one area, the signal is recorded and the central-station monitor notifies the customer. A second alarm signal - received in an adjacent zone in close time proximity, is the confirmation the central-station monitor needs to request a dispatch immediately. This builds in increased protection and a fail safe should a door blow open or a bird rattle an exterior window.

### ***Enhanced Call Verification***

Enhanced Call Verification (ECV) helps reduce false dispatches 25-50% while still protecting citizens, and is mandated in several US jurisdictions, although the alarm industry has successfully opposed it in others. ECV requires central station personnel to attempt to verify the alarm activation by making a minimum of two phone calls to two different responsible party telephone numbers before dispatching law enforcement to the scene.

The first alarm-verification call goes to the location the alarm originated. If contact with a person is not made a second call is placed to a different number. The secondary number, best practices dictate, should be to a telephone that is answered even after hours, preferably a cellular phone of a decision maker authorized to request or bypass emergency response.

### ***Video verification***

Video verification documents a change in local conditions by using cameras to record video signals or image snapshots. The source images can be sent over a communication link, usually an Internet protocol (IP) network, to the central station where monitors retrieve the images through proprietary software. The information is then relayed to law-enforcement and recorded to an event file, which can later be used as prosecution evidence.

An example of how this system works is when a passive infrared or other sensor is triggered a designated number of video frames from before and after the event is sent to the central station.

A second video solution can be incorporated into to a standard panel, which sends the central station an alarm. When a signal is received, a trained monitoring professional

accesses the on-site digital video recorder (DVR) through an IP link to determine the cause of the activation. For this type of system, the camera input to the DVR reflects the alarm panel's zones and partitioning, which allows personnel to look for an alarm source in multiple areas.

### ***Independent certification***

Some insurance companies and local agencies require that alarm systems be installed to code or be certified by an independent third party. Independent certification ensures a system meets a level of criteria above and beyond what a sales representative may offer. The alarm system is required to have a maintenance check carried out every 6 – 12 months (in the UK, 'Audible Only' intruder alarm systems require a routine service visit once every 12 months and monitored intruder alarm systems require a check twice in every 12 month period) to ensure all internal components, sensors and PSUs are functioning correctly. In the past, this would require an alarm service engineer to attend site and carry the checks out. With the use of the Internet and a compatible IP transmitting device (at the alarmed premises) some checks can now be carried out remotely from the central station. This insures you have a system that will be reliable when needed. 3rd party alarm certifying agencies include:

- your local fire department
- Your building department
- (UL) Underwriters Laboratories
- (NFPA) National Fire Protection Association
- (NEC) National Electrical Code
- (NFBAA) National Fire & Burglar Alarm Association
- (CSAA) Central Station Alarm Association
- BAFE - British Approvals for Fire Equipment (UK Market)
- FSA - Fire and Security Association (UK Market)
- NSI - National Security Inspectorate (UK Market)
- ISIA - Irish Security Industry Association
- SSAIB - Security & Alarms Inspection Board (UK & ROI)
- VdS VdS Schadenverhütung Germany
  - - The fire department & building department set standards and inspect as needed. U.L is the only certification entity. The other associations set guidelines.

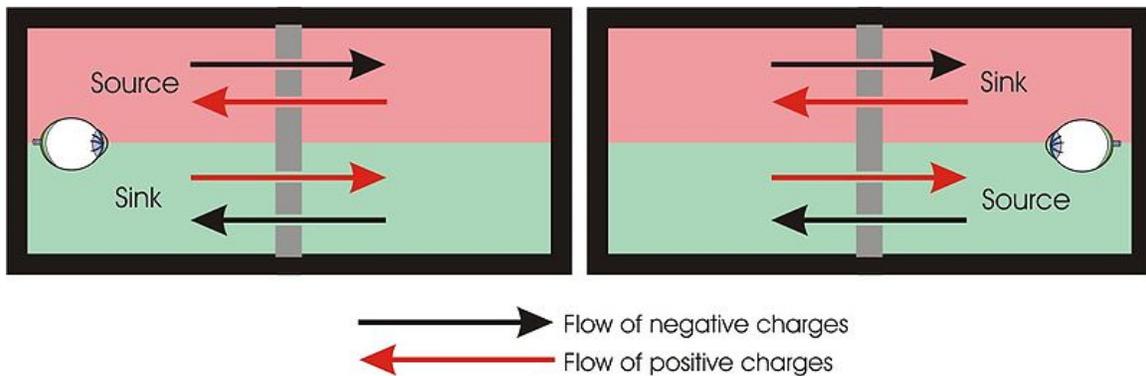
## Chapter 8

# Current Sources and Sinks & Load Profile

## Current Sources and Sinks

**Current sources and sinks** are analysis formalisms which distinguish points, areas, or volumes through which current enters or exits a system. While current sources or sinks are abstract elements used for analysis, generally they have physical counterparts in real-world applications; e.g. the anode or cathode in a battery. In all cases, each of the opposing terms (source or sink) may refer to the same object, depending on the perspective of the observer and the sign convention being used; there is no intrinsic difference between a source and a sink.

In some cases, the term current source refers to a boundary where current flows from locations where it is not measured to locations where it is measured. In a similar fashion, a current sink may refer to the boundary where current flows from locations where it is measured to locations where it is not measured. By analogy to the flow of water, a current source would be like a mountain spring - water flows from its source (a hidden location underground) to the surface where it is easily observed. Using the same analogy, a current sink would be like water flowing down a drain - water travels from where it is observed to where it is not observed.



Two-compartment model illustrating the definition of a current sink vs source.

Shown at right is a general two-compartment model to help illustrate the definition of current sources or sinks. In this two-compartment model, the compartments are separated by a semi-conductive barrier (gray). An observer, symbolized by the eye, can "see" only one compartment at a time. Red arrows indicate the direction of flow of positive charges, while black arrows indicate the direction of flow of negative charges. The pink and green backgrounds are meant to symbolize different configurations, configuration 1 when charges are flowing in one direction and configuration 2 when they are flowing in the opposite direction. The difference between the left and right panels is simply the location of the "eye".

A source or a sink is defined by which compartment is viewable by the observer.

- A **source** is:
  - A flow of positive charges from the "invisible" to the "visible" compartment (i.e. toward the eye), or...
  - A flow of negative charges from the "visible" to the "invisible" (away from the eye).
- A **sink** is:
  - A flow of positive charges "away from the eye", or...
  - A flow of negative charges "toward the eye".

In biology, the schematic barrier in the figure could represent a cell membrane, and as a result, the two compartments could represent the inside and the outside of the cell. Generally speaking the point of observation would be outside the cell. Thus the cell would be termed a sink with respect to any flow of positive charges into it, and the cell would act as a source for any positive charges flowing out of it. Note that when considering the flow of negative charges, the definitions are reversed.

### ***Current sources and sinks in neurobiology***

Current sources and sinks have proven to be very valuable in the study of brain function. Both have particular relevance in electrophysiology. Two examples of the study of

sources and sinks are Electroencephalography (EEG) and Current Source Density Analysis (extracellular field potentials).

### ***Current source density analysis***

Current source density analysis (which could more accurately be called current source and sink density analysis) is the practice of placing a microelectrode in proximity to a nerve or a nerve cell to detect current sourcing from or sinking into their plasma membranes. When positive charges, for example, flow quickly across a plasma membrane to the inside of a cell (sink) this creates a transient cloud of negativity in the vicinity of the sink. This is because the flow of positive charges into the interior of the cell leaves behind uncompensated negative charges. A nearby micro-electrode with substantial tip resistance (on the order of 1 MΩ) can detect that negativity because a voltage difference will develop across the tip of the electrode (between the negativity outside the electrode, and the electroneutral environment inside the electrode). Put another way, the electrode internal solution will donate some of the positive charge needed to compensate the negativity caused by the current sink. Thus, the inside of the electrode will become negative relative to ground for as long as the extracellular negativity persists. The extracellular negativity will persist as long as the current sink is present. Thus, by measuring a negativity relative to ground, the electrode indirectly reports the presence of a nearby current sink. The size of the recorded negativity will vary directly with the size of the current sink and inversely with the distance between the electrode and the sink.

The relationship between the sum of the current sources and sinks and the voltage measured by the microelectrode probe may be calculated analytically if it is assumed that the quasi-static assumption holds, that the medium is spherically symmetric, homogeneous, isotropic, and infinite, and if the current source or sink is modeled as a point source. The relationship is given by:

$$\Phi(r) = \frac{I}{4\pi r \sigma}$$

where  $\Phi$  is the potential at radius  $r$  from the source or sink, which passes current  $I$  through a medium with conductivity  $\sigma$ .

## **Load Profile**

In electrical engineering, a **load profile** is a graph of the variation in the electrical load versus time. A load profile will vary according to customer type (typical examples include residential, commercial and industrial), temperature and holiday seasons.

## ***Power generation***

In the electricity generation sector, a load curve is a chart showing the amount of electricity customers use over a period of time. Generation companies use this information to plan how much power they will need to generate at any given time. A load duration curve is similar to a load curve. The information is the same but is presented in a different form. These curves are useful in the selection of generator units for supplying electricity.

## ***Electricity distribution***

In an electricity distribution network, the load profile of electricity usage is important to the efficiency and reliability of power transmission. The power transformer or battery-to-grid are critical aspects of power distribution and sizing and modelling of batteries or transformers depends on the load profile. The factory specification of transformers for the optimization of load losses versus no-load losses is dependent directly on the characteristics of the load profile that the transformer is expected to be subjected to. This includes such characteristics as average load factor, utilization factor, and responsibility factor, which can all be calculated based on a given load profile.

A transformer typically has a cyclic rating allowing for the variation in the load profile. This cyclic rating allows the transformer to be overloaded at peak times so long as there is a sufficient cooling down period at the lower point in the load profile.

## ***Retail energy markets***

In retail energy markets, supplier obligations are settled on an hourly or subhourly basis. For most customers, consumption is measured on a monthly basis, based on meter reading schedules. Load profiles are used to convert the monthly consumption data into estimates of hourly or subhourly consumption in order to determine the supplier obligation. For each hour, these estimates are aggregated for all customers of an energy supplier, and the aggregate amount is used in market settlement calculations as the total demand that must be covered by the supplier.

## ***Calculating a load profile***

Load profiles can be determined by direct metering but on smaller devices such as distribution network transformers this is not routinely done. Instead a load profile can be inferred from customer billing or other data. An example of a practical calculation used by utilities is using a transformer's maximum demand reading and taking into account the known number of each customer type supplied by these transformers. This process is called load research.

## ***Recording load profiles***

Actual demand can be collected at strategic locations to perform more detailed load analysis; this is beneficial to both distribution and end-user customers looking for peak consumption. Smart grid meters, utility meter load profilers, data logging sub-meters and portable data loggers are designed to accomplish this task by recording readings at a set interval.

## Chapter 9

# IEC Standards

## IEC 60269

In electrical engineering, **IEC 60269** refers to a set of technical standards 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.

- IEC 60269-1 - Low-voltage fuses - Part 1: General requirements
- IEC 60269-2 - Low-voltage fuses - Part 2: Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application) - Examples of standardized systems of fuses A to I
- IEC 60269-3 - Low-voltage fuses - Part 3: Supplementary requirements for fuses for use by unskilled persons (fuses mainly for household and similar applications) - Examples of standardized systems of fuses A to F
- IEC 60269-4 - Low-voltage fuses - Part 4: Supplementary requirements for fuse-links for the protection of semiconductor devices
- IEC 60269-5 - Low-voltage fuses - Part 5: Guidance for the application of low-voltage fuses
- IEC 60269-6 - Low-voltage fuses - Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems

In IEC standards, the replaceable element is called a *fuse link* and the assembly of fuse link and fuse holder is called a *fuse*. North American standards call the replaceable element only the *fuse*.

## ***Application categories and time-current characteristics***

IEC 60269 unifies the electrical characteristics of fuses that are dimensionally interchangeable with fuses built to earlier British, German, French or Italian standards. The standard identifies *application categories* which classify the time-current characteristic of each type of fuse. The application category is a two-digit code.

- The first letter is *a* if the fuse is for short-circuit protection only; an *associated* device must provide overload protection.
- The first letter is *g* if the fuse is intended to operate even with currents as low as those that cause it to blow in one hour. These are considered *general-purpose* fuses for protection of wires.

The second letter indicates the type of equipment or system to be protected:

- D North American time-delay fuses for motor circuits, UL 248 fuses
- G General purpose protection of wires and cables
- M Motors
- N Conductors sized to North American practice, UL 248 fuses
- PV Solar Photovoltaic Arrays as per 60269-6
- R, S - rectifiers or semiconductors
- Tr Transformers

Any fuses built to the IEC 60269 standard and carrying the same application category (for example, gG or aM) will have similar electrical characteristics, time-current characteristics, power dissipation as any other, even if the fuses are made in the packages standardized to the earlier national standards. Fuses of the same application category can be substituted for each other provided the voltage rating of the circuit does not exceed the fuse rating.

### ***D type fuses***

D-type (Diazed) fuse cartridges have a bottle-shaped ceramic body with metal end caps and are fitted in screw-in fuse holders. They are available in five different body sizes, with ratings from 2 A up to 200 A (see table). The designation of a size consists of the letter *D* and a Roman numeral. Higher-voltage types rated up to 750 V have increased clearance distances and are longer than lower-voltage-rated fuses.



DIAZED fuse element D II (right) and cylindrical fuseholder

D0-type (Neozed) fuses are similar but have a smaller, cylindrical body. They are available in three different sizes with ratings from 2 A up to 100 A (see table).

In some jurisdictions, replacement of the fuse cartridge by unskilled personnel is allowed only for fuses up to a certain maximum rating. If the fuse cartridge is inserted into the socket without the cap, a shock hazard exists.

Fuseholders may be secured by screws to a panel, attached to bus bars, or mounted on DIN rails. For the Neozed fuses, there are also fuse bases with integrated disconnecting switches. Changing fuses with the circuit off increases the safety of the user. With new versions of these load disconnecting switches, the fuse cartridges are no longer screwed, but are held by spring clips.

The smaller end cap (the "top" of the bottle) has a diameter that varies with the fuse rating: higher ratings have wider end caps. The fixed part of the fuse holder contains a (usually colour-coded) gauge ring, which will accept end caps up to a certain diameter. It is therefore not possible to fit a fuse of a higher rating than allowed for by the gauge ring.

The size of the gauge ring is determined by the current rating of the circuit to be protected. Gauge rings are intended to be changed only by authorized personnel.

The larger end cap (the "bottom" of the bottle) has at its centre a small spring loaded button retained by a thin wire, which serves as a "fuse blown" indicator. When the fuse blows, the wire breaks and the indicator button is ejected by the spring. A missing or displaced indicator thus pinpoints a blown fuse. The removable part of the fuse holder has a small window to allow inspection of the indicator without removal of the fuse. The indicator button usually has a coloured dot indicating the fuse rating (see table).

D- and D0-type fuses are used for protection of circuits up to 500 V AC in residential and commercial installations, and occasionally for the protection of electric motors. The most common operating class is gG (general purpose, formerly gL), but other classes are available. A gG class fuse will typically blow within 2–5 seconds at five times the rated current, and within 0.1–0.2 seconds at ten times the rated current.

2 A	4 A	6 A	10 A	13 A	16 A	20 A	25 A
 Pink	 Brown	 Green	 Red	 Black	 Grey	 Blue	 Yellow
32 A	35 A	40 A	50 A	63 A	80 A	100 A	
 Black	 Black	 Black	 White	 Copper	 Silver	 Red	
125 A	160 A	200 A					
 Yellow	 Copper	 Blue					

## D-system (DIAZED)



D<sub>III</sub> fuses 50 A, 35 A  
 D<sub>II</sub> fuses 25 A, 20 A, 16 A

Size	Designated current	Thread
D <sub>I</sub> (Swiss)	2 A, 4 A, 6 A, 10 A, 16 A	SE21
D <sub>I</sub> (NDz)	2 A, 4 A, 6 A, 10 A, 16 A, 20 A, 25 A	E16
D <sub>II</sub>	2 A, 4 A, 6 A, 10 A, 13 A, 16 A, 20 A, 25 A	E27
D <sub>III</sub>	35 A, 40 A, 50 A, 63 A	E33
D <sub>IV</sub>	80 A, 100 A	G 1¼"
D <sub>V</sub>	125 A, 160 A, 200 A	G 2"

- The sizes D<sub>IV</sub> and D<sub>V</sub> are rarely used
- D<sub>I</sub> and D<sub>V</sub> are not part of IEC 60269 (meet outdated national standards)



## D01 fuse cartridge 16A (Neozed)



Neozed Fuse block for 3-phase AC

### **D0-System (NEOZED)**

Fuses of the D0 system (read as *D zero*) or NEOZED are smaller than the DIAZED fuses. NEOZED fuses are divided into three sizes.

<b>Size</b>	<b>Rated current</b>	<b>Thread</b>
D01 2 A, 4 A, 6 A, 10 A, 13 A, 16 A		E14
D02 20 A, 25 A, 32 A, 35 A, 40 A, 50 A, 63 A		E18
D03 80 A, 100 A		M 30 × 2

The D03 size is used very rarely, because with these high currents NH fuses have proven to be more reliable. In circuits with a high short-circuit current level, D-fuses cannot be used and type NH fuses are used instead.

## ***NH-fuses***



An NH fuse rated 250 A with alarm unit

NH fuses have a square or oblong body and blade-style terminals. These fuses are larger and have higher ratings than the screw type fuses, up to 1.25 kA. NH fuses are widespread in industrial plants as well as in public mains electricity applications, e.g., in electrical substations and electrical distribution boards, or in house junction boxes in buildings.

NH fuses can be changed with power on the circuit, but this requires special training, special tools, and personal protective equipment. An isolation protection mat and isolating gloves may be necessary. Pulling any fuse cartridge under load can cause an electric arc, which may cause serious and fatal injuries without protection equipment. *NH disconnecting switches* facilitate the safety of cartridge replacement.

NH fuses are manufactured in several current rating ranges.

<b>Size</b>	<b>Current range (A)</b>	<b>Approx. blade length (mm)</b>
00/000	6–160	78
0	6–160	125
1	80–250	135
2	125–400	150
3	315–630	150
4	500–1,000	200
4a	500–1,250	200

## ***British domestic fuses***

In British residential installations, cylindrical fuses with a diameter of  $\frac{1}{4}$  inch and a length of 1 inch ( $\text{Ø } 6.3 \times 25.4 \text{ mm}$ ) in compliance with British Standard BS 1362 are found inside a standard UK 13 A plug. The specification calls for sand-filled fuses with a ceramic body and metallic contacts at the ends with a 5.5 mm length.

## **IEC 61508**

**IEC 61508** is an international standard of rules applied in industry. It is titled "Functional safety of electrical/electronic/programmable electronic safety-related systems".

IEC 61508 is intended to be a basic functional safety standard applicable to all kinds of industry. It defines functional safety as: "part of the overall safety relating to the EUC (Equipment Under Control) and the EUC control system which depends on the correct functioning of the E/E/PE safety-related systems, other technology safety-related systems and external risk reduction facilities."

The standard covers the complete safety life cycle, and may need interpretation to develop sector specific standards. It has its origins in the process control industry sector.

The safety life cycle has 16 phases which roughly can be divided into three groups as follows: phases 1-5 address analysis, phases 6-13 address realisation and phases 14-16 address operation. All phases are concerned with the safety function of the system. The standard has seven parts. Parts 1-3 contain the requirements of the standard (normative), while 4-7 are guidelines and examples for development and thus informative.

Central to the standard are the concepts of risk and safety function. The risk is a function of frequency (or likelihood) of the hazardous event and the event consequence severity. The risk is reduced to a tolerable level by applying safety functions which may consist of E/E/PES and/or other technologies. While other technologies may be employed in reducing the risk, only those safety functions relying on E/E/PES are covered by the detailed requirements of IEC 61508.

IEC 61508 has the following views on risks:

- zero risk can never be reached
- safety must be considered from the beginning
- non-tolerable risks must be reduced (ALARP)

## ***Testing Software To IEC 61508***

Software written in accordance with IEC 61508, may need to be Unit Tested, depending upon the SIL level it needs to achieve. The main requirement in Unit Testing is to ensure that the software is fully tested at the function level and that all possible branches and

paths are taken through the software. In some higher SIL level applications the software code coverage requirement is much tougher and an MCDC coverage criteria is used rather than simple branch coverage. To obtain the MCDC (modified condition decision coverage) coverage information you will need a Unit Testing tool, sometime referred to as a Software Module Testing tool.

## **IEC 61511**

**IEC 61511** is a technical standard which sets out practices in the engineering of systems that ensure the safety of an industrial process through the use of instrumentation. Such systems are referred to as *Safety Instrumented Systems*. The title of the standard is "*Functional safety - Safety instrumented systems for the process industry sector*".

### **Scope**

The process industry sector includes many types of manufacturing processes, such as refineries, petrochemical, chemical, pharmaceutical, pulp and paper, and power. The process sector standard does not cover nuclear power facilities or nuclear reactors. IEC 61511 covers the application of electrical, electronic and programmable electronic equipment. While IEC 61511 does apply to equipment using pneumatic or hydraulic systems to manipulate final elements, the standard does not cover the design and implementation of pneumatic or hydraulic logic solvers.

This standard defines the functional safety requirements established by IEC 61508 in process industry sector terminology. IEC 61511 focuses attention on one type of instrumented safety system used within the process sector, the Safety Instrumented System (SIS). The standard does not provide requirements for other instrumented safety systems, such as fire and gas systems, safety alarms, or safety controls.

### **History**

In 1998 the IEC, which stands for International Electrotechnical Commission published a document, IEC 61508, entitled: "Functional safety of electrical/electronic/programmable electronic safety-related systems". This document sets the standards for safety-related system design of hardware and software. IEC 61508 is generic functional safety standard, providing the framework and core requirements for sector specific standard. Three sector specific standards have been released using the IEC 61508 framework, IEC 61511 (process), IEC 61513 (nuclear) and IEC 62061 (manufacturing). IEC 61511 provides good engineering practices for the application of safety instrumented systems in the process sector.

In the United States ANSI/ISA 84.00.01-2004 was issued in September 2004. It primarily mirrors IEC 61511 in content with the exception that it contains a grandfathering clause:

For existing safety instrumented systems (SIS) designed and constructed in accordance with codes, standards, or practices prior to the issuance of this standard (e.g. ANSI/ISA 84.01-1996), the owner/operator shall determine and document that the equipment is designed, maintained, inspected, tested, and operated in a safe manner.

The European standards body, CENELEC, has adopted the standard as EN 61511. This means that in each of the member states of the European Union, the standard is published as a national standard. For example, in Great Britain, it is published by the national standards body, BSI, as BS EN 61511. The content of these national publications is identical to that of IEC 61511. Note, however, that 61511 is not harmonized under any directive of the European Commission.

## ***The Standard***

IEC 61511 covers the design and management requirements for SISs from cradle to grave. Its scope includes: initial concept, design, implementation, operation, and maintenance through to decommissioning. It starts in the earliest phase of a project and continues through startup. It contains sections that cover modifications that come along later, along with maintenance activities and the eventual decommissioning activities.

The standard consists of three parts:

1. Framework, definitions, system, hardware and software requirements
2. Guidelines in the application of IEC 61511-1
3. Guidance for the determination of the required safety integrity levels

ISA 84.01/IEC 61511 requires a management system for identified SIS. An SIS is composed of a separate and independent combination of sensors, logic solvers, final elements, and support systems that are designed and managed to achieve a specified safety integrity level (SIL). An SIS may implement one or more safety instrumented functions (SIFs), which are designed and implemented to address a specific process hazard or hazardous event. The SIS management system should define how an owner/operator intends to assess, design, engineer, verify, install, commission, validate, operate, maintain, and continuously improve their SIS. The essential roles of the various personnel assigned responsibility for the SIS should be defined and procedures developed, as necessary, to support the consistent execution of their responsibilities.

ISA 84.01/IEC 61511 uses an order of magnitude metric, the SIL, to establish the necessary performance. A hazard and risk analysis is used to identify the required safety functions and risk reduction for specified hazardous events. Safety functions allocated to the SIS are safety instrumented functions; the allocated risk reduction is related to the SIL. The design and operating basis is developed to ensure that the SIS meets the required SIL. Field data are collected through operational and mechanical integrity program activities to assess actual SIS performance. When the required performance is not met, action should be taken to close the gap, ensuring safe and reliable operation.

## Chapter 10

# Pro Electron and Single-Phase Electric Power

## Pro Electron

**Pro Electron** is the European type designation and registration system for active components (such as semiconductors, liquid crystal displays, sensor devices, electronic tubes and cathode ray tubes).

Pro Electron was set up in 1966 in Brussels, Belgium. In 1983 it was merged with the European Electronic Component Manufacturers Association (EECA) and since then operates as an agency of the EECA.

The goal of Pro Electron is to allow unambiguous identification of electronic parts, even when made by several different manufacturers. To this end, manufacturers register new devices with the agency and receive new type designators for them.

Examples of Pro Electron type designators are:

- AD162 -- germanium power transistor for audio frequency use
- BY133 -- silicon rectifier
- BZY88C5V1 -- 5.1V Zener diode
- CQY97 -- light emitting diode
- ECC83 -- 6.3V heater noval dual triode
- A63EAA00XX01 -- Color TV picture tube
- SAA1300 -- Digital integrated circuit

Pro Electron took the popular European coding system in use from around 1934 for valves (tubes), the Mullard-Philips tube designation, and essentially re-allocated several of the rarely-used heater designations (first letter of the part number) for semiconductors, and continued the use of the second letters "A" for signal diode, "C" for low-power bipolar transistor or triode, "D" for high power transistor (or triode), and "Y" for rectifier. Beyond that, the tube and transistor type letter conventions start to diverge, e.g. "L" for



# Single-Phase Electric Power

In electrical engineering, **single-phase electric power** refers to the distribution of alternating current electric power using a system in which all the voltages of the supply vary in unison. Single-phase distribution is used when loads are mostly lighting and heating, with few large electric motors. A single-phase supply connected to an alternating current electric motor does not produce a revolving magnetic field; single-phase motors need additional circuits for starting, and such motors are uncommon above 10 or 20 kW in rating.

In contrast, in a three-phase system, the currents in each conductor reach their peak instantaneous values sequentially, not simultaneously; in each cycle of the power frequency, first one, then the second, then the third current reaches its maximum value. The waveforms of the three supply conductors are offset from one another in time (delayed in phase) by one-third of their period.

Standard frequencies of single-phase power systems are either 50 or 60 Hz. Special single-phase traction power networks may operate at 16.67 Hz or other frequencies to power electric railways.

## ***Splitting out***



Single phase polemount stepdown transformer (Canadian).

No arrangement of transformers can convert a single-phase load into a balanced load on a polyphase system. A single-phase load may be powered from a three-phase distribution system either by connection between a phase and neutral or by connecting the load between two phases. The load device must be designed for the voltage in each case. The neutral point in a three phase system exists at the mathematical center of an equilateral triangle formed by the three phase points, and the phase-to-phase voltage is accordingly  $\sqrt{3}$  times the phase-to-neutral voltage. For example, in places using a 415 volt 3 phase

system, the phase-to-neutral voltage is 240 volts, allowing single-phase lighting to be connected phase-to-neutral and three-phase motors to be connected to all three phases.

In North America, a typical three-phase system will have 208 volts between the phases and 120 volts between phase and neutral. If heating equipment designed for the 240-volt three-wire single phase system is connected to two phases of a 208 volt supply, it will only produce 75% of its rated heating effect. Single-phase motors may have taps to allow their use on either 208 V or 240 V supplies.

On higher voltage systems (kilovolts) where a single phase transformer is in use to supply a low voltage system the method of splitting varies. In North American utility distribution practice, the primary of the step-down transformer is wired across a single high voltage feed wire and neutral, at least for smaller supplies. Rural distribution may be a single phase at a medium voltage; in some areas single wire earth return distribution is used when customers are very far apart. In Britain the step-down primary is wired phase-phase.

## ***Applications***

Single-phase power distribution is widely used especially in rural areas, where the cost of a three-phase distribution network is high and motor loads are small and uncommon.

High power systems, say, hundreds of kVA or larger, are nearly always three phase. The largest supply normally available as single phase varies according to the standards of the electrical utility. In the UK a single-phase household supply may be rated 100 A or even 125 A, meaning that there is little need for 3 phase in a domestic or small commercial environment. Much of the rest of Europe has traditionally had much smaller limits on the size of single phase supplies resulting in even houses being supplied with 3 phase (in urban areas with three-phase supply networks).

In North America, individual residences and small commercial buildings with services up to about 100 kV·A (417 amperes at 240 volts) will usually have three-wire single-phase distribution, often with only one customer per distribution transformer. In exceptional cases larger single-phase three-wire services can be provided, usually only in remote areas where poly-phase distribution is not available. In rural areas farmers who wish to use three-phase motors may install a phase converter if only a single-phase supply is available. Larger consumers such as large buildings, shopping centers, factories, office blocks, and multiple-unit apartment blocks will have three-phase service. In densely populated areas of cities, network power distribution is used with many customers and many supply transformers connected to provide hundreds or thousands of kV·A, a load concentrated over a few hundred square meters.

Three-wire single-phase systems are rarely used in the UK where large loads are needed off only two high voltage phases.

Single-phase power may be used for electric railways; the largest single-phase generator in the world, at Neckarwestheim Nuclear Power Plant, supplies a railway system on a dedicated traction power network.

## ***Grounding***

Typically a third conductor, called **ground** (or "safety ground") (U.S.) or **protective earth** (Europe, IEC), is used as a protection against electric shock, and ordinarily only carries significant current when there is a circuit fault. Several different earthing systems are in use.

## Chapter 11

# Ring Circuit

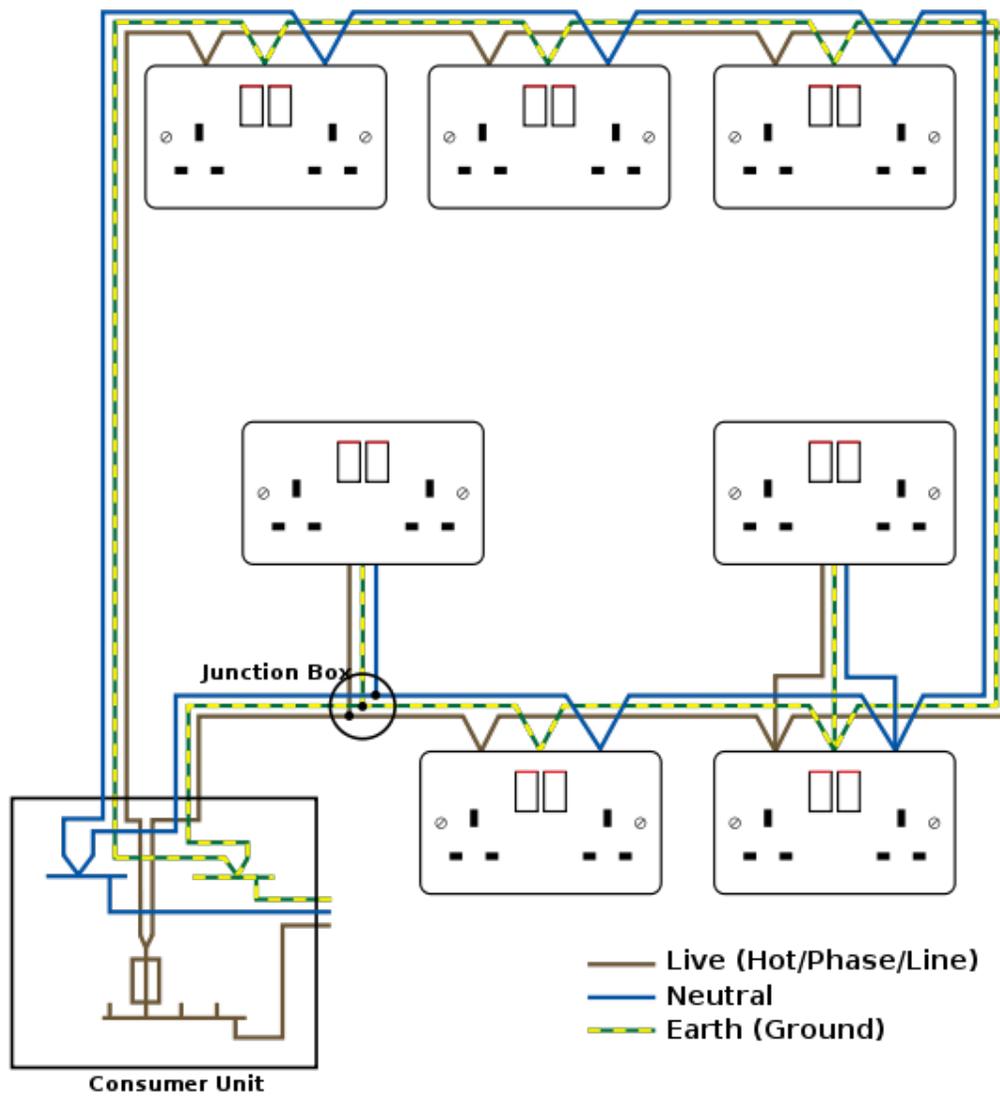


Diagram of a possible configuration of ring final circuit. Consumer unit (fuse box) is at bottom left.

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

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

## ***Description***

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

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

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

## ***History and use***

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

The ring main came about because Britain had to embark on a massive rebuilding programme following World War II. There was an acute shortage of copper, and it was necessary to devise a scheme that used less copper than would normally be the case. The scheme was specified to use 13 A fused socket outlets, and several designs for the plugs and sockets appeared. Only the square pin (BS 1363) system survives, but the round pin

Dorman & Smith system was still in use in many locations well into the 1980s, and is still occasionally seen today. This latter plug had the distinctive feature that the fuse was also the live pin and unscrewed from the plug body.

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

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

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

### ***Installation rules***

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

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

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

Unfused spurs from a ring wired in the same cable as the ring are allowed to run one single or double socket from each of the sockets on the ring (the use of two singles was previously allowed but was banned because of people replacing them with doubles) or one fused connection unit (FCU). Spurs may either start from a socket or be joined to the

ring cable with a junction box or other approved method of joining cables. Triple and larger sockets are generally fused and therefore can also be placed on a spur.

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

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

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

## ***Criticism***

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

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

## **Fault conditions are not apparent when in use**

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

- Part of the ring missing or loose connections result in 2.5 mm<sup>2</sup> cables running above rated current at times, resulting in reduced cable life.
  - Radials with a loose connection will overheat severely and be an immediate fire risk.
  - Radials with a broken connection will not function (if L or N broken), or function with no safety earth connection (if E broken).
- Accidental cross connection between two 32 A rings means that the fault current protection reaches 64 A and the required fault disconnection times are violated grossly.
  - Testing at installation addresses this.

- Ring spur installations encourage using three connectors in one terminal, which can cause one to become loose and overheat.
  - The same situation occurs with both radial and ring circuits when branching off is used.
- Rings encourage the installation of too many spurs on a ring, leading to a risk of overheating, especially if spur cables are too long without adequate fusing at the spur-point (i.e. a BS5733 or similar fused spur is not used) - although this is almost certainly a breach of the appropriate electrical standards (e.g. BS7671 in the UK).

## Complexity of safety tests

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

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

## Balancing requirement

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

## Electromagnetic interference

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

In a ring circuit, on the other hand, it is possible that the live and neutral currents are not equal on each side of the ring. Mains-frequency currents follow the path of least resistance, and it is possible, especially with aging oxidized contacts, that from a socket, the lowest-resistance *live* connection is along the left-hand side of the ring, and the lowest-resistance *neutral* connection is along the right-hand side. As a result, current is flowing *around* the ring and will therefore induce a magnetic field. In the extreme case of a defect ring circuit, the live connection could become completely interrupted on one side of the ring and the neutral connection on the other, and then the full current would supply

the magnetic field. This can lead to substantial electromagnetic interference, such as mains hum in audio devices, accidental triggering of alarm and protection devices (burglar alarms, RCDs, etc.), malfunctions of consumer electronics and medical devices, ground loops, etc.

## **Overcurrent protection**

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

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

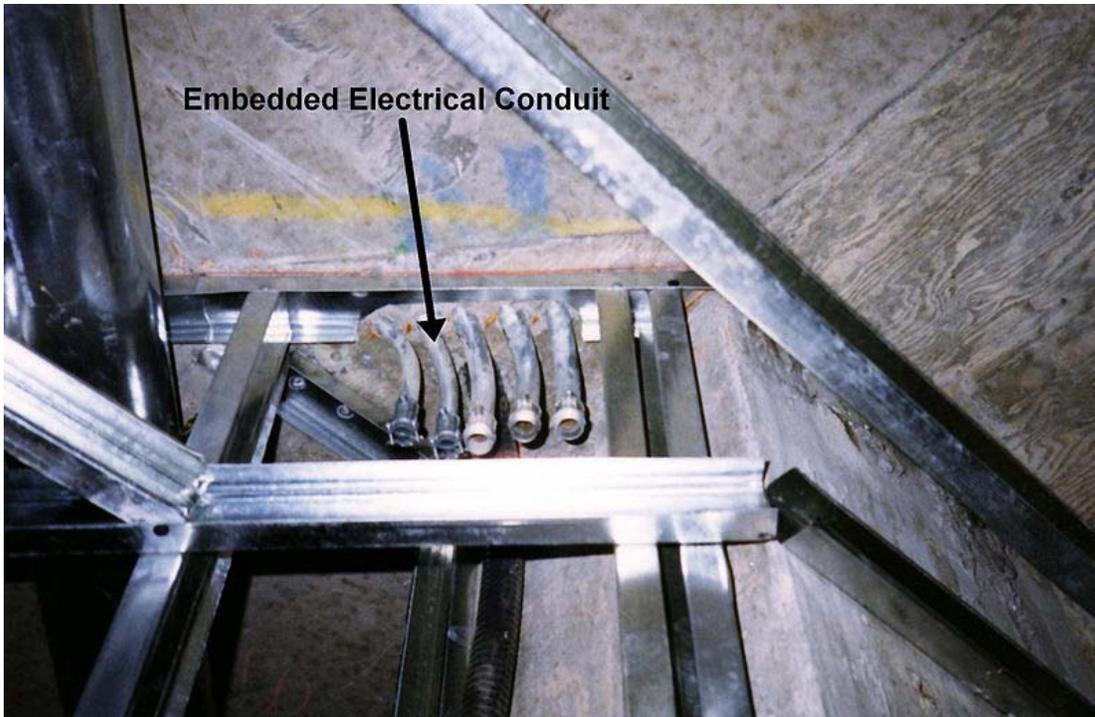
One theoretical advantage of individually-fused plugs is that a faulty appliance or flexible cord has a high likelihood of blowing only its plug-top fuse, leaving other appliances on the same ring circuit operating. However, with the introduction of EN60898 mcb's and the increased use of RCD protection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

## Chapter 12

# Electrical Conduit



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



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



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

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

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

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

### ***Comparison with other wiring methods***

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

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

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

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

The cost of conduit installation is higher than other wiring methods due to the cost of materials and labor. In applications such as residential construction, the high degree of physical damage protection is not required so the expense of conduit is not warranted. Conductors installed within conduit cannot dissipate heat as readily as those installed in

open wiring, so the current capacity of each conductor must be reduced if many are installed in one conduit. It is impractical, and prohibited by wiring regulations, to have more than 360 degrees of total bends in a run of conduit, so special outlet fittings must be provided to allow conductors to be installed without damage in such runs. While metal conduit can be used as a grounding conductor, the circuit length is limited. A long run of conduit as grounding conductor will not allow proper operation of overcurrent devices on a fault, for example.

### ***Types of conduit***

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

#### **Rigid Metal Conduit (RMC)**

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

#### **Rigid Nonmetallic Conduit (RNC)**

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

#### **Galvanized rigid conduit (GRC)**

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

#### **Electrical metallic tubing (EMT)**

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

#### **Electrical Nonmetallic Tubing (ENT)**

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

## Flexible Metallic Conduit (FMC)



Flexible metallic conduit used in an underground parking facility.

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

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

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

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

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

## **Liquidtight Flexible Metal Conduit (LFMC)**

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

## **Flexible Metallic Tubing (FMT)**

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

## **Liquidtight Flexible Nonmetallic Conduit (LFNC)**

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

## **Aluminum conduit**

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

## **Intermediate metal conduit (IMC)**

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

## **PVC conduit**

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

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



Plastic tubing for use as electrical conduit.

### **Other metal conduits**

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

### **Underground conduit**

Large diameter (more than 2 inch/50 mm) conduit may be installed underground between buildings to allow installation of power and communication cables. An assembly of these conduits, often called a duct bank, may either be directly buried in earth or encased in concrete. A duct bank will allow replacement of damaged cables between buildings or additional power and communications circuits to be added, without the expense of excavation of a trench. While metal conduit is occasionally used for burial, usually PVC,

polyethylene or polystyrene plastics are now used due to lower cost. Formerly, compressed asbestos fiber mixed with cement was used for some underground installations. Telephone and communications circuits were installed in fired-clay conduit.

### ***Comparison of some types of conduit***

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

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

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

### ***Fittings***

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

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

*Couplings* connect two pieces of conduit together.

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

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

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

## Conduit bodies

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

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

- L-shaped bodies ("Ells") include the LB, LL, and LR, where the inlet is in line with the access cover and the outlet is on the back, left and right, respectively. In addition to providing access to wires for pulling, "L" fittings allow a 90 degree turn in conduit where there is insufficient space for a full-radius 90 degree sweep (curved conduit section).
- T-shaped bodies ("Tees") feature an inlet in line with the access cover and outlets to both the cover's left and right.
- C-shaped bodies ("Cees") have identical openings above and below the access cover, and are used to pull conductors in a straight runs as they make no turn between inlet and outlet.
- Service "Ells" (SLBs), shorter with inlets flush with the access cover, are frequently used where a circuit passes through an exterior wall from outside to inside.

## Other wireways

### Surface Mounted Raceway (wire molding)

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

#### Advantages

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

## Disadvantages

- Its appearance may not be acceptable to all observers.

## Trunking

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

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

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

## ***Passive fire protection***

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