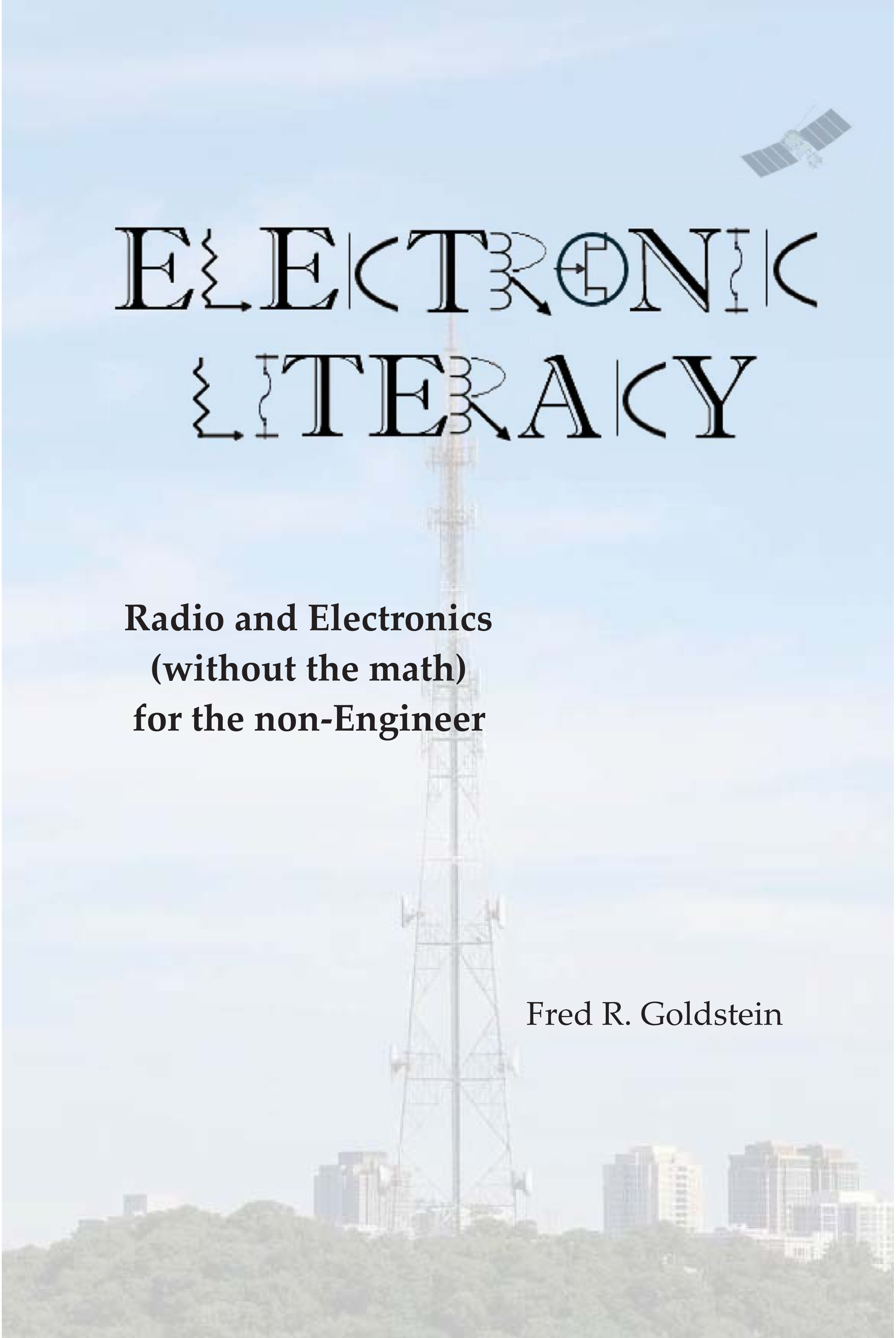


# ELECTRONIC LITERACY

## Radio and Electronics
## (without the math)
## for the non-Engineer

Fred R. Goldstein

# Electronic Literacy

## Radio and Electronics (without the math) for the non-engineer

*Fred R. Goldstein*
*Interisle Consulting Group*

V1.0 May 2026

(ebook edition 19-May-2026)

# Contents

# Preface

The field of electronics is central to modern life, but each advance seems to make it harder to understand. Many books have been written to teach electronics, each usually focused on one or another specific type of audience. At one extreme, some introductory and hobbyist-oriented books demonstrate how electronic circuits can be applied, and may feature simple construction projects, but don't spend much time on the underlying theory. Then there are the license manuals and study guides aimed at specific qualifications, such as passing amateur radio examinations or other certifications. These may focus on certain aspects of electronics, or even just on exam questions, and are targeted at narrow audiences.

Textbooks aimed at university level electrical engineering courses, while important for "EE" majors, are very heavily oriented towards mathematical formulas and analysis. They teach the theory in a largely mathematical manner. That is of course important for their target audience; no one seeks a degree in EE without good math skills, and math is critically important for many engineering tasks. But such texts are inaccessible to many people who are interested in electronics at a more basic craft, technician, or hobbyist level, or who are not as proficient at math.

The goal here, then, is to provide an approachable introduction to electronics and radio that is *not* aimed at one or another specific type of audience, and which does not depend on an understanding of even high school math, such as geometry, trigonometry, or calculus. Only the most basic formulas and simple algebra are used here where necessary. Certainly a degree of numeracy helps, as one must feel fairly comfortable with numbers to deal with electronics, but it's a long way from the basic "My Dear Aunt Sally" order of operations to calculus and trigonometry. Aunt Sally may have a place here, but her mathematician cousins are elsewhere. Study questions are intentionally omitted – literacy is not about memorization of facts, but about broad familiarization with the field.

This, then, is what electronic literacy is about: It's a high-level familiarity with a broad range of critical concepts that underlie electronics in general, and especially with regard to radio, also called wireless, communications. It's like what literacy is to reading and writing, and what numeracy is to math – it's the first step from exposure towards expertise. It's the language, terminology, and symbolism, and what it applies to. It's not the detailed memorization of circuit designs and formulas; it's the background needed to know when those formulas and designs might be applied, whether by a user or by an engineer. This book also does not describe computer circuits or digital electronics in great detail – such texts are quite plentiful, and many simply take the underlying electronic principles for granted.

Who, then, is this introduction aimed at? A broad range of readers should benefit. Hobbyists, of course – budding "makers" and radio amateurs among them. Also professionals and technicians who work with radio, including those working with mobile telephone networks, land mobile and public safety systems, broadcasting, microwave, satellites, and fixed wireless networks. Students who are considering a career in electronics or even enrolling in a course of study in EE may also find this useful as a way to pick up some general understanding before having to delve into the math. And it's for any other members of the general public who are curious about one of the most important fields of technology.

I'd also like to acknowledge the assistance of Dan Grossman in helping to improve this work.

# 1 DC basics

Electricity is the form of energy that consists of electrons moving through a conductor. The most basic principles of electricity are the ones that deal with direct current – DC – wherein the flow is continuous in the same direction. In the real world, most electronics deal with much more complicated flows than that, which get us into alternating current – AC – and that includes the circuits used to send and receive radio waves ("wireless"). But the principles for dealing with AC are built upon a foundation of DC.

Electrons are *charged* particles. For historic reasons, an electron's charge is called *negative*. Like charges repel; opposite charges attract. So in a DC circuit, electrons flow from the negative side to the positive side of a source (like a battery). Yes, this sounds backwards, but Ben Franklin didn't know that at the time… so the nucleus of an atom contains protons, which have a positive charge, while the electrons have a negative charge, and they must in the end balance out.

That's why electrical devices are called *circuits*. That comes from the fact that electricity goes around, like in a circle, from one side to another. Electrons don't just go out; they come back.

The most basic DC circuit, then, can be modeled as a source and a sink. A good example of a DC source is a battery. A good example of a sink is an old-fashioned incandescent light bulb. That's really just a type of *resistor*, something that conducts electricity but not perfectly and thus converts some of its energy to heat. In an incandescent bulb, the kind that Edison's employee invented for him, the filament gets so hot that it glows. Edison himself thought that domestic electricity should be DC; incandescent light bulbs don't care if they're given AC or DC. He was wrong, but we'll get to that later when discussing the power grid.

*Standard schematic symbols of battery and resistor*

When describing electrical circuits in writing, we use *schematic* diagrams. These show what connects where and use standard symbols to represent each type of component. To be honest, schematics of modern digital circuits aren't nearly as useful as the ones of old-fashioned analog ones, because so much of a digital circuit is hidden inside complex chips (integrated circuits), which are just represented by squares or rectangles. (Some integrated circuits contain billions of components.) But for understanding how electronics and radio work, the older analog models, and schematic diagrams, are more helpful. The reference section at the end of this book shows the schematic symbols for all of the common discrete electronic components.

## Electrical power

Electricity is a form of energy, of power, and it has two major components. One is the rate of the electron flow (symbolized by the capital letter I) – how many electrons are flowing through a conductor at a given time. The size of the flow is measured in amperes, often just called amps. An ampere[1] represents one coulomb of electrons flowing per second. A coulomb is a specific very large number[2] of electrons. Thus the size of the flow is often referred to as amperage.

The other major component is the *electromotive force* (EMF, thus the symbol E) – how much pressure, in effect, is being applied to the flow. The basic unit of electromotive force is the volt (symbolized by the letter V). Power (P), then, is the product of flow (amps) times EMF (volts), and is measured in watts (W). So if you have 1 amp flowing at 100 volts, then you have 100 watts.

---

[1] Many units of measurement are named for people, often 19th century pioneers. Their symbols are thus capitalized, so an ampere is A. Units that are not named for people are not capitalized.

[2] $6.241509\times10^{18}$, to be specific, though they are officially referred to as "elementary charge", not specifically electrons.

And if you have 0.1 amp flowing at 1000 volts, you also have 100 watts. And if you have 10 amps at 10 volts, you still have 100 watts. Represented mathematically, then, it's a simple formula: P=EI. Via very simple algebra, then E=P/I and I=P/E. Or this simple mnemonic diagram, where you put your (virtual or real) thumb over what you're looking for and get the formula for it:

$$\frac{P}{E\ I}$$

## Ohm's Law

The other basic formula for DC circuits, which still applies alongside some additional factors in AC circuits, is Ohm's Law. This tells how much current will flow through a given circuit, given a specific amount of electromotive force (voltage) and resistance. DC resistance is measured in Ohms (symbolized by Ω, the Greek letter Omega). Ohm's Law is central to electrical circuits in general, a foundational principal. It is also quite simple: E=IR. That is, volts (E) = amps (I) times ohms (R) . And thus I=E/R and R=E/I. Or, using our old friend the thumb, just remember

$$\frac{E}{I\ R}$$

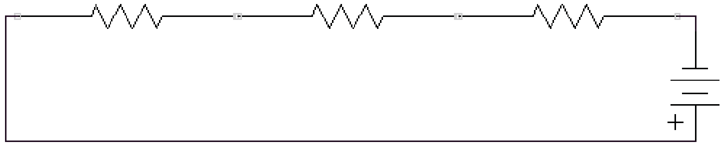
Thus if you have a resistance of 100 ohms and put a 1.5 volt source across it, E/R = 1.5/100 = 0.015 amps (that is, 15 milliamps) will flow. If you have a circuit that draws 2 amps and is fed at 12 volts, then the effective resistance is E/I = 12/2 = 6 ohms. If you have 100 milliamps flowing through a 1000-ohm resistance, then the voltage is IR = .1*1000=100 volts.

From Ohm's Law, then, if you double the voltage, twice the current will flow. And from the power formula, if you double the voltage and as a result also double the current, then four times the power will flow. Thus $P = E^2R = I^2R$.

## Series and parallel circuits

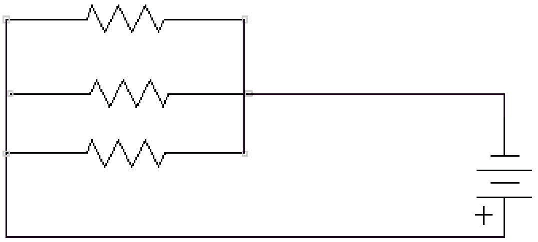
Another set of basic rules applies when you have more than one component in the circuit, which in the real world is *always*. When two resistances are *in series* with one another, then the total resistance is simply the sum of the resistances.

Even the wires that carry power to a component have resistance. All conductors have *some* resistance. (Except for superconductors, but those are pretty exotic, and they have to be kept at extremely low temperatures to maintain their superconductivity.) Thus when a 100-ohm resistance is wired with two conductors, one at either side, that each have one ohm of resistance, then the total resistance is 102 ohms.



*Series circuit*

If two resistances are *in parallel* with one another, then the total *current* is simply the sum of the two currents. (Think of two things plugged in at once.)

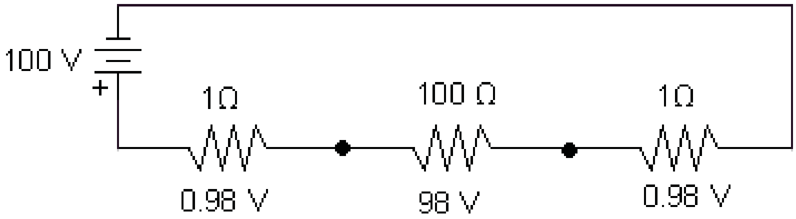


*Parallel circuit*

And thus the effective resistance $R=E/(I_1+I_2)$, and thus computed by adding up the *inverses* of the resistances, which determine the current flow through each:

$R=1/((1/R_1)+(1/R_2)\ldots)$

The series part is particularly interesting when dealing with the real-world resistances of conductors. Wires are, in a sense, resistors too. When you have series resistances, the *voltage drop*, which is the effective voltage seen by a component, is proportionate to its share of the total resistance. Feeding 100 volts into the aforementioned circuit, with 1 ohm on either side of a 100-ohm resistance, does not produce 1 amp of current. It produces (100/102) about 0.98 amps total flow, because the total resistance is 102Ω . And each 1-ohm conductor, effectively a spread-out resistor, has its own voltage drop of (1/102) 0.98 volts. And that leaves just over 98 volts for the load.



*Voltage drop across each resistance, including the effective resistance of the wires to the actual load.*

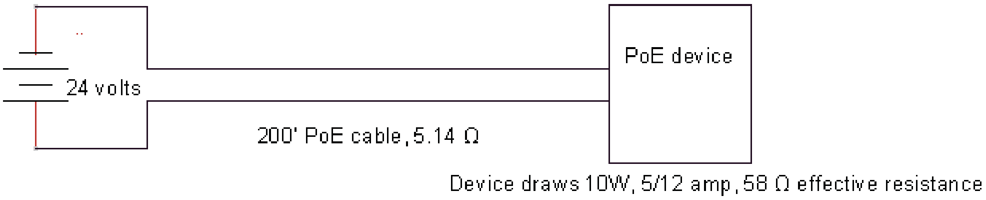
Resistors are actually energy conversion devices. They turn electrical power into heat. Heating elements such as electric space heaters and toasters are just big resistors. Tungsten wire is most commonly used for that; it is a mediocre conductor, so it heats up easily, and has a high melting point, so it stays intact.

Since wire has resistance, an amount of heat is generated by the power lost to it. Continuing with the example, P=EI, so if .98 amps flows through a voltage drop of 0.98 volts, then about .96 watts are converted to heat. 20-gauge wire has a resistance of 1.015 ohms per 100 feet, which is close to the example.

Fires have started from overloaded wires. So you don't want to run too much amperage through any conductors. Household wiring (it's AC, but in this case it doesn't make much difference) usually uses 14-gauge wire to support a peak load of 20 amps. Its resistance is about 0.252Ω per 100 feet. Much more than 20A makes it dangerously hot. (Capacity of different wire gauges is discussed in more detail in Chapter 4 below.)

That's what circuit breakers and fuses are for. A fuse is a short piece of conductor designed to melt and thus open the circuit (break the flow) when more current flows than its rating. A circuit breaker trips – opens the circuit – when current exceeds its design value, but unlike a fuse it can be reset without replacement. Tripping may be thermal, caused by a resistive element overheating, or can be magnetic, caused by current flowing through an electromagnetic solenoid. Thermal breakers, like slow-blow fuses, are generally more tolerant of short current spikes than magnetic ones. Both have their uses.

For a more modern application, take Power over Ethernet (PoE), a very common way of powering communications devices ranging from telephone sets to outdoor radios. PoE is a "low voltage" source, which means that it is no more than 56 volts, and thus is considered safer to handle than household AC (117 volts in the U.S. and Canada, up to 240 volts in Europe and many other countries) or other higher voltages. 24 volt PoE is common. Category 5E Ethernet cable uses 24 gauge wire. That has a typical DC resistance of 2.57Ω per 100 feet. If a tower-mounted radio needed 10 watts of power, and were fed at 24 volts, then it would draw 5/12 amp and thus have an effective resistance of about 58Ω.  If fed via 100 feet of this cable, with two conductors of 24-gauge wire, then the total wire resistance (200 feet) would be 5.14Ω, almost a tenth of the total, and have a substantial impact on the power flowing to the device. 48 volt PoE would be much more suitable.



*Impact of cable resistance in Power over Ethernet*

Let's go back to our old friend Edison and his love of DC. After commercializing the electric light, he set out to sell electrical generating and distribution systems. (For a time, he controlled a little company called General Electric.) He believed in DC power, sending 100 volts or so from the power plant to the home. But that resulted in a lot of *ohmic* losses in the wire, so users had to be quite close to a power plant, and total loads couldn't be very large.

His arch-rival, George Westinghouse, believed in AC systems. Why? Because a simple device, the *transformer*, could change the ratio of voltage to current, and thus reduce the impact of the wire resistance by operating long transmission systems at higher voltage than what was ultimately delivered to the end user. Considering that ohmic losses are proportional to resistance, and R=E/I, a higher voltage and lower amperage in the desired load will reduce the fraction of total resistance, and thus ohmic losses, in the power transmission lines. A 15,000-volt line (city distribution lines, as found on top of many poles, feeding transformers, are often called "15,000 volt" though the actual voltage is usually somewhat lower) will have less than 1% of the loss of a 120-volt line. Hence Edison lost "the war of the currents". He couldn't defeat Ohm's Law.

Ironically, DC has come back with the emergence of high-voltage semiconductor rectifiers and DC-to-AC converters. It is used in long-distance high-voltage transmission lines, when connecting together electric power grids, and in large data centers. What goes around comes around! But household power remains AC. And transformers are still far more common in most of the power system.

## Measuring current and voltage

In fact, the DC-powered electromagnet provided us with the most fundamental way to measure current and, by inference, voltage. The strength of the magnetic field created by an electromagnet is proportionate to the current flow. So measuring the magnetism measures the current. The most common type of analog current measuring device is the D’Arsonval meter movement. This consists of a moving coil on a pivot inside a permanent magnet, with a spring. As current passes through the coil, electromagnetism, which is proportional to current flow, moves it, and an indicator needle attached to it shows how much current is flowing.

A meter can be built for different levels of sensitivity. Some meters will go to full scale with a fraction of a milliamp; others will take much higher current. But remembering how parallel circuits work, high current can be measured with a more sensitive meter by putting a low resistance but known *shunt* resistor (current divider) in parallel with the meter. If the meter has a DC resistance of (let’s make the math easy) 99 ohms, and the shunt is 1 ohm, then 1% of the current will flow through the meter and thus a 1-milliamp meter movement will indicate a 100-milliamp flow at full scale.

To measure voltage, Ohm’s Law gives us the answer. We know that I=E/R. So if we put a high-resistance resistor in series with a meter, and connect them in parallel to a circuit, the current (I) in amps will be voltage divided by the resistance (ohms). For example, take a 1-milliamp meter and put a 1 megohm (1MΩ) resistor in series. Full scale (.001A) will occur at 1000 volts (1000/1,000,000). And we can scale the full-scale voltage by switching resistors.

*Volt-Ohm-Milliameter (VOM) from the 1970s*

One of the most basic analog test instruments is the volt-ohm-milliameter ("VOM", or multimeter). It has a meter movement and a range switch. Current ranges are changed by selecting different shunt resistances. Voltage ranges are changed by selecting different series resistances. What about the Ohms? Resistance is measured by using an internal battery to feed a known voltage across the two probes. Since R=E/I and E is known, R is indicated by the flow of current (I), and thus the more current, the lower the resistance.

Modern multimeters use solid-state components instead of the old magnetic meter movements, but the principles of the old VOM still apply.

## Switches and relays

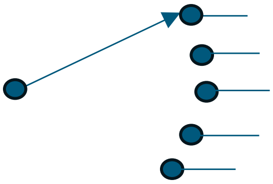
A switch is a device that makes or breaks connections between conductors. Switches have a standard nomenclature. The simplest type of switch is called a *single-pole single-throw* (SPST), where a *pole* is the conductor being switched and the *throw* is the number of potential "on" positions. So a light switch may be SPST if it switches one side of the circuit to the light socket.

*SPST switch*

But switches come in many varieties. For one thing, a switch needs to have sufficient current-handling capacity as well as sufficient voltage isolation capacity. Switches that handle radio frequencies have to deal with additional parameters.

A single-pole double-throw (SPDT) switch selects between two different conductors. A "three way" room lighting arrangement, where two switches control the same light, uses double-throw switches: Two wires run in series between the two switches, one to each throw. When both switches are set so that the and thus the lights are on when both switches are set to the throw connecting to the same conductor, the circuit is closed and the light is on. Clever and simple.

Multi-pole switches are used in many devices too, so that, for example, two circuits can be switched simultaneously with one action. Multi-throw switches are also common, often in a rotary format where selection is turning the dial, though multi-position slide switches are also common. Hence, for example, this 1P5T 5-way rotary dial switch:

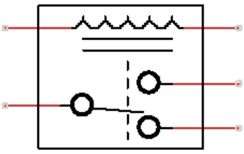


*1P5T (one pole 5 throw) switch*

One important detail about switches is that they can be either *shorting* or *non-shorting*. When turning the dial, a shorting (or "make before break") switch connects the second throw before disconnecting the first. This also creates a brief connection, through the pole, between the two throws. A non-shorting (or "break before make") switch leaves the pole momentarily disconnected. Both have their applications, and it is important to pay attention when designing one into a circuit.

A relay is a switch activated by an electromagnet. Relays, like switches, come in many sizes. Huge ones are used to switch the power grid. Tiny ones are used inside many devices to handle signals or small voltages. Some are sealed in a vacuum to operate faster and more cleanly. Specialized relays were even wired up to perform logic functions, before computers took over. Before computers became a practical alternative, relays were used in industrial Programmable Logic Controllers (PLCs) for process control, and as building blocks of telephone exchange switches.

Like other switches, relays can have different numbers of poles and throw positions. Also, a path through a relay is considered *normally-open* (NO) if it is not connected when the relay is not charged, and *normally-closed* (NC) if it is. A double-throw relay thus has an NO and an NC side.



*SPDT relay*

## Kirchoff’s Law and Circuits

Pretty much everything electronic is in the form of some kind or other of *circuit*. The very word circuit is, not coincidentally, related to circle – it’s about electrons going around from one point to another, a source to a sink. A Formula 1 race car drives on a circuit; electronic components form circuits.

One fundamental law defining how all circuits work is *Kirchoff’s Law*. This states that the sum of currents flowing in to any node (junction) of a circuit is equal to the current flowing out of it. Another way of describing it is that charge, like all kinds of energy, is conserved; electrons don’t accumulate anywhere in a circuit. That’s actually Kirchoff’s first law, his current law; his second law, about voltage, is similar: The directed sum of the potential differences (voltages) around any closed loop is zero. But they really say the same thing; what goes in comes out, so they’re usually treated as one.

Kirchoff’s Law applies to DC and AC circuits. It’s as fundamental as Ohm’s Law but doesn’t really need a formula to apply most of the time, though of course there are mathematical formulas for those who need them. It’s really most useful to consider as a principle that every circuit must conform to.

## Ground

While electrons nominally flow from the negative to the positive side of a power source, many real-world devices and systems treat one side of the power as a sort of common reference point, one that other voltages can be routed or compared to as required. And that common point is most often called *ground*, for the good reason that most often, for safety purposes, it *is* tied to the actual ground. (In the UK, the equivalent term is “earth”.)

In a schematic diagram, then, the symbol for ground is quite often used.

*The 3-pronged symbol is sometimes favored for chassis ground while the triangular-line symbol is sometimes favored for actual earth (e.g., ground rod) grounds.*

Thus the power system in a typical automobile will be described as “12 volt negative ground”, meaning that the negative terminal of the battery is tied to the actual metal chassis of the car and only positive voltages are supplied to devices in the car. (A car’s rubber tires are not exactly good conductors but they’re not perfect insulators either, especially when wet.)

More visibly, a common AC line (mains) plug will often have three pins. Two are the nominal AC circuit and the third, if there is one (it’s not required on all devices), is simply a safety connection to ground. Even the standard 2-pin electrical socket has actually one “hot” side and one “neutral” side that is connected to ground. (In the type of plugs used in the United States and some other countries, the wider side is the neutral.)

The third wire, tied to ground, was added years after that standard was adopted. Unlike the neutral, it is connected to some metal part of the device and is never supposed to carry current. Its importance becomes apparent if there is a fault, and the hot conductor gets short circuited to some part of the appliance, making it also hot. If somebody touches a metal part of an ungrounded appliance with that kind of fault, they get a potentially dangerous shock. There is also risk of an electrical fire. The ground wire conducts the fault current away from the appliance, possibly causing the circuit breaker to trip, because the original ground is often inadequate for safety purposes. A light switch, then, must be wired to switch the hot side, not the ground side, of the circuit. Also, the ground wire must never, ever be connected to an energized load in order to carry current.

Another advantage of keeping things properly grounded is that lightning does not tend to strike well-grounded objects but strikes things that allow a charge to accumulate. Trees, for example, attract lightning, and a lightning rod is a grounded rod on top of a building that exists more to dissipate electrical charges that build up in a storm than to absorb a lightning strike, though that happens too. Lightning is a big burst of static electricity that can release hundreds or more of amps at once, possibly causing severe damage and sometimes starting fires.

The actual ground, as in soil, is not a perfect conductor. Its conductance (the inverse of resistance) varies with local geology and conditions; wet ground, not surprisingly, conducts better than dry ground. Because ground conductors are not perfect and not everything is well grounded, different devices within a complex system (like a radio station) may not have exactly the same ground potential unless they are carefully tied together and then tied to a good outside grounding system (i.e., ground rod). Some houses use a cold water pipe as a ground reference but that is not always the safest way. Indeed when dealing with sensitive electronics, grounding is a fine art as well as a science, and proper systems design can take a lot of engineering. But ordinarily, just using ground terminals when provided and using ground rods when appropriate is an important safety measure.

# 2 AC Basics

The vast majority of electrical devices do not operate entirely with DC. Alternating current – AC – includes everything from the electrical outlet on the wall to the microwave signal going to and from the antenna, from audio going to the speaker to the video signals displayed on a television screen. If a signal is present, if any information is present, then there's AC.

AC is current that changes direction or level, rather than have a fixed voltage with a positive and negative side. The simplest kind is what's used for power, so let's discuss that first. And that begins with electromagnets.

If you put an electric current through a coil of wire wound on a magnetic (e.g., iron) core, then a magnetic field will be generated. That's your most basic electromagnet, and works with DC too, and such magnets are themselves useful for many purposes.

## AC electromagnetism

A more interesting property occurs when the magnetic field changes. Changes in magnetism *induce* the flow of electrical current into nearby conductors. If you take a permanent magnet and move it rapidly past a coil wound on a magnetic core, then an electrical current will be formed in the coil. Hence if you take a magnetic rotor and surround it with coils, and turn the rotor, the coils will produce electricity. That becomes an electrical generator. Power it with an engine of some kind and you have a power plant. The most efficient generators create AC, as the current reverses direction as the north and south poles of the magnet pass the coil.

The same principle works in reverse. Alternating current in a stator can cause a magnetic rotor to turn. That's an electric motor. In fact the only difference between a motor and a generator is how it's used – apply motion and it's a generator,