ELEMENTS OF ELECTRONIC COMMUNICATIONS

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To Julian Brown, "Uncle Julian"
who filled a void in my life for many years

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Elements of Electronic Communications

Preface

That electronic communications has changed the world we live in is no secret, and this observation is not particularly astute or clever. What started three-quarters of a century ago, in the form of an ozone stench and the pulsating spark of the shipboard radiotelegrapher, is now a multibillion dollar business employing thousands of engineers, operators, and technicians. The amateur and professional alike participate daily in feats of communications, now ordinary, that would have created a furor only a generation ago. Synchronous satellites orbit the earth and are used not only to relay voice communications, but computer data and television signals as well.

Despite complexity of modern communications equipment, the basics have not changed very much—and that is the subject of this book. From here, you should be able to go on to pass the Federal Communications Commission license examinations and do quite well earning your living in communications electronics. Also, you could use electronics and communications as your hobby. Although this book is not especially written for those aspiring to ham radio, it is excellent preparation. In fact, the relationship is mutual—amateur radio is excellent preparation for a profession in electronic communications. Building and operating your own amateur radio station will give you experience, insight, and "savvy"—that inexplicable but necessary quality that no book will ever give. More information about this hobby can be obtained from The American Radio Relay League, 225 Main Street, Newington, Connecticut, 06111.

JOSEPH J. CARR

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1 Fundamentals of Electricity

1.1 THE ATOM

All matter is composed of building blocks called *atoms*. Each atom is composed of still smaller particles that are not unique to any particular chemical element. Three major particles are known; these are called electrons, protons, and neutrons. The first two of these carry equal, but opposite polarity, electric charges. The electron carries a negative (−) charge that is equal in magnitude to the positive (+) charge on the proton. The neutron carries no electric charge, so it is said to be electrically neutral.

The physical and chemical properties of any element are determined by the makeup of its atoms. In particular are the number of protons and electrons used to make up the atom. Figure 1.1(a) shows a model of the structure of the simplest atom, that of the element hydrogen. We now know that this particular model is oversimplified, but it remains sufficiently valid for discussions at this level.

The central core of the atom, called the *nucleus,* contains positively charged protons and electrically neutral neutrons. The masses of the protons and neutrons are very nearly identical, so the nucleus has a mass that reflects the total number of both protons and neutrons. In hydrogen there is but one proton.

In an electrically neutral atom there is only one electron for each proton. In the hydrogen atom, therefore, there is a single electron orbiting about the nucleus. Helium, on the other hand, has two protons in the nucleus, so it has two orbital electrons. Again, we see electrical neutrality, because there are exactly as many electrons as there are protons.

The distance between the nucleus and the orbital electrons is not arbitrary, but is subject to some specific restrictions. The reasons that this is true are beyond the scope of this book, but are taken up in a subject called "quantum mechanics" (a branch of physics). For our purposes let us say that there are only certain allowable distances and that these form imaginary shells around the nucleus. Each shell has a maximum electron holding capacity. Any electrons in excess of that magic number must go into the next higher shell until it, in turn, is full of electrons. The first shell, that nearest the nucleus, can hold only two electrons. If an atom has

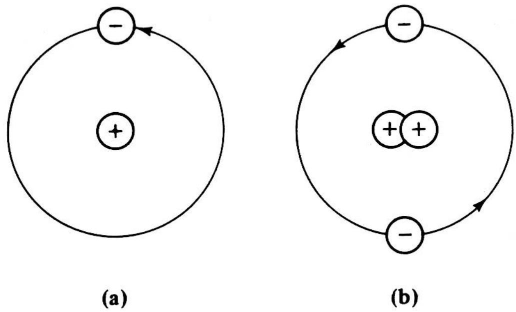


Figure 1.1 The atom of hydrogen has one electron and one proton, while the atom of helium has two electrons and two protons.

more than two electrons, more than one shell will be needed. The element lithium, for example, has three electrons and three protons. Two of the electrons completely fill the first shell, so the third is forced to enter the second shell. This shell is filled when it contains eight electrons, while the third shell can accommodate up to eighteen electrons.

Atoms in which the electrons are tightly bound to the nucleus do not give them up easily. In those materials it takes a relatively large amount of energy to break loose any electrons. Other materials, notably acids and metals, have weakly bound outer electrons. In that type of material it takes very little additional energy to strip free large numbers of electrons. Even the random motion of atoms caused by thermal agitation at room temperature is sufficient to cause large numbers of free electrons. In the absence of any external forces, these electrons drift about almost aimlessly inside of the material until they find some atom in need of an electron to complete its complement and restore electrical neutrality. An atom that has fewer than its normal quantity of electrons is called a *positive ion,* whereas one in which there is an extra electron present is a *negative ion.*

1.2 STATIC ELECTRICITY

Some materials give up electrons if merely rubbed hard by certain other materials. An electrical charge then exists on the surface of the materials. This is the source of the static charges built up on your body when you walk across a rug, pet a cat, or slide across your car seat. One of the two touching surfaces takes on a positive charge, while the other takes on a negative charge.

Surrounding any electrical charge is an electric field. When such fields are stationary, and do not move, the field is said to be electrostatic. If, on the other hand, the charges move, then an electrical current is said to exist.

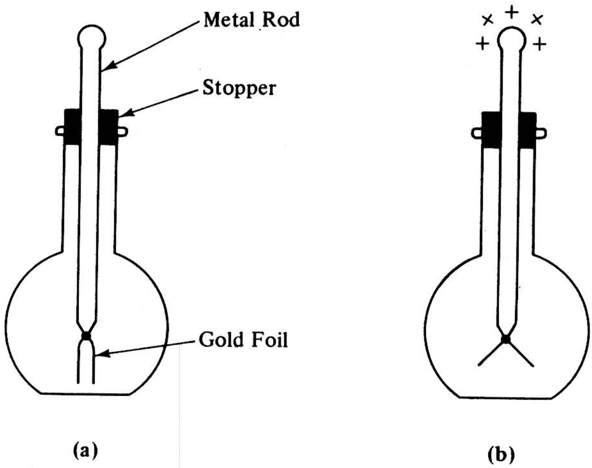


Figure 1.2 The electroscope (a) uncharged, and (b) charged.

An electroscope (See Figure 1.2) is a simple instrument used to detect the presence of a static electric charge. When there is no charge nearby, we find the gold leaves hanging limp. Application of an electric charge, whether positive or negative, will cause the foil pieces to spread apart. This occurs because the two pieces each receive a charge of the same polarity. A fundamental fact to commit to memory is that *unlike charges attract* and *like charges repel each other*. (See Figure 1.3.)

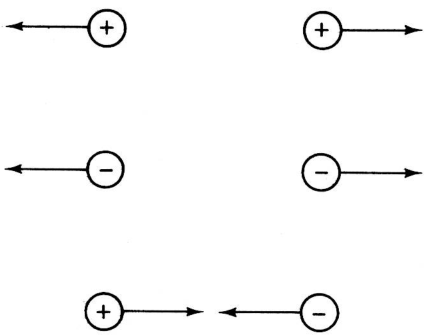


Figure 1.3 *Like* charges repel, and *unlike* charges attract each other.

Review. Before proceeding on to the material of the next section, let us take a moment to quickly review the high points of the preceding material.

1. Atoms are the building blocks of matter, and are composed of negatively charged particles called electrons, positively charged particles called protons and electrically neutral (no charge) particles called neutrons.

2. Protons and neutrons form a central core in the atom called the nucleus. Electrons are found orbiting around the nucleus. Neutrons and protons have approximately the same weight, but the electron is roughly 1850 times lighter than either neutrons or protons.
3. Loosely bound electrons can become free electrons with the application of very little extra energy. If static electric charges move, then an electric current exists.
4. "Like" charges (+ and +, or − and −) repel each other, while unlike charges (− and +) attract each other.

1.3 ELECTRIC CURRENT

If free electrons travel in the same general direction, an electric current is said to exist. Normal motion of free electrons due to thermal and other forms of energy inside the material is random, and not so well ordered that it could be called an electrical current. An external force, however, can cause a large number of electrons to migrate in the same general direction, and that is what constitutes the electrical current.

In the electronics field we say that electron flow is from negative to positive. Do not become confused when you hear some people loudly and vehemently defend the notion that just the opposite is true. In physics courses, and those electrical courses intended mostly for electricians, they often teach it that way. This does not reflect a fundamental ignorance of electrical theory, but the fact that current flow is defined in two different ways. In both cases, however, it is electrons that actually move. The problem with directional flow began in the eighteenth century when early investigators into electrical phenomena, such as Benjamin Franklin, discovered two polarities and arbitrarily assigned (+) and (−) polarities. In electronics work we assign the (−) symbol to the terminal of the battery or other source that has the *excess of electrons*. The (+) terminal has a deficiency of electrons. Nature seems to love equilibrium, so the electrons flow from the area of excess (−) to the areas of deficiency (+). This seems to make good sense in light of the fact that an area with an excess of the negative electrons has a net charge that is negative, justifying use of the (−) symbol. Similarly, the (+) symbol for the terminal with a deficiency seems justified by the fact that there is a net positive charge at that terminal. The other fields assign a (−) symbol for a deficiency and a (+) symbol for an excess. When speaking to electronics people, or taking examinations intended for electronics people (i.e., the FCC license exams), use the electronics definition—current flows from *negative to positive*.

Electrons cannot flow in an "orderly manner" without some external

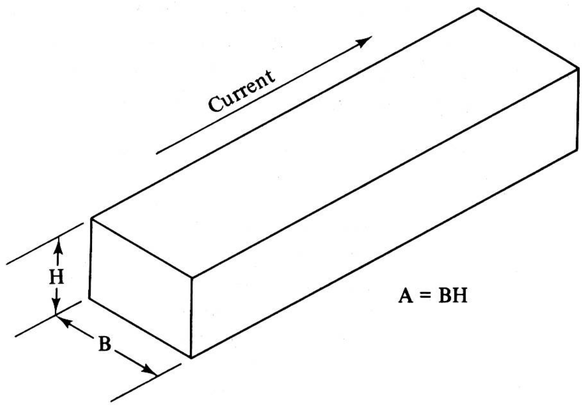


Figure 1.4 Electrical resistance of a conductor is directly proportional to the length and resistivity, and *inversely* proportional to the cross-sectional area.

force's being applied. This force is called various names including "electromotive force" (EMF), "electric(al) potential," "potential difference," "potential," or "voltage." All are correct and may be used interchangeably. Voltage tends to set electrons in motion, thereby setting up an electric current. *Resistance* is a property of materials that tends to oppose the flow of electric current. It is a function of the cross-sectional area, temperature, and a property called *resistivity,* which is specific to the particular material in which the current is flowing. The exact relationship between the factors affecting resistance is that resistance is inversely proportional to the cross-sectional area, and directly proportional to resistivity and length. (See Figure 1.4.) In mathematical form:

$$R = \rho \times \frac{L}{A} \tag{1-1}$$

where ρ (Greek letter "rho") is resistivity.
L is the length.
A is the cross-sectional area.

The units for resistivity are "meter-ohms" if metric units are used for L and A, or "ohms/circular mil foot" if feet are used for length and circular mils are used for cross-sectional area.

Not all materials are good electrical conductors. Some materials, like metals, contain large numbers of free electrons, and these can produce large values of electrical current flow with very little applied force. Other materials, though, have tightly bound outer electrons, and consequently are not able to support an electrical current flow. These materials are called "insulators," examples of which are listed in the chart of Figure 1.5. Since insulators have few free electrons, it takes an extremely large value of voltage to produce any appreciable current flow in those materials.

An "insulator" has few free electrons, whereas a "conductor" has many free electrons.

Conductors	Insulators
Carbon	Dry air
Acids	Ceramics
Metals	Dry wood
	Glass
	Rubber
	Resins

Figure 1.5 Some common conductors and insulators.

1.4 THE "PLUMBING ANALOGY" OF ELECTRICITY

The flow of electricity has often been likened to the flow of water in a hydraulic system. Indeed, the word "current" seems to have come from the fact that Benjamin Franklin and his early colleagues viewed electricity as some kind of strange, unseen, fluid phenomenon.

We know that electrons flow from a region where they are in excess to a region where they are deficient in numbers. This is analogous to the water system of Figure 1.6. Notice that the level in the right-hand container is lower than the level of water in the left-hand container. The difference between the two fluid heights is the potential difference of the system, so is analogous to voltage—the potential energy of electrical systems. The actual forces applied to the two containers are gravitational, so there will be a potential difference only when the heights are unequal. Under that condition water (i.e., current) will flow from the left side to the right side until the water levels in the two containers are equal. This will, then, make the potential difference zero, so the flow of water ceases. This is also true of electrical circuits. A battery, for instance, is dead when the potential difference between the terminals is zero—or 0 volts, if you prefer.

An even stronger version of the plumbing analogy brings in the concept of an electric circuit, because it is a closed loop. We can visualize such a system to have a pump that supplies the pressure (potential) to force water through the pipes of a hydraulic "circuit," which returns to the suction side of the pump. This is very much like the situation existing

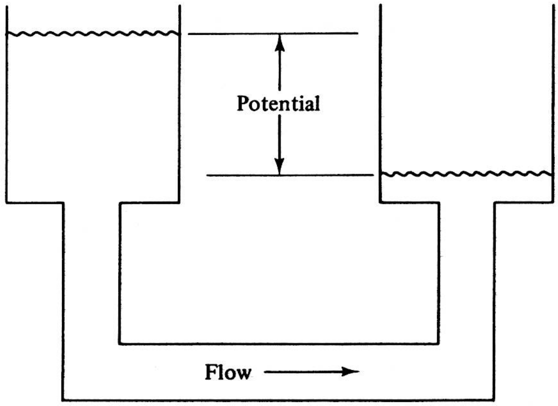


Figure 1.6 Electrical current flow is analogous to water flow in a plumbing system.

when a battery, or other electrical source, forces electrons through an electrical circuit. The pump is similar in function to an electrical generator, which maintains a potential difference so long as it is turning.

We know that voltage, or EMF, is much like a pressure in a hydraulic system; both are examples of forces, or force differences. Furthermore, we can see how the flow of water is similar to the flow of electrons through an electrical circuit. But where is the analogy to electrical resistance? The plumbing analogy would not hold up unless it also provided some property similar to electrical resistance, which it fortunately does: the constriction of the pipe walls. A pipe, or any other hydraulic conduit, can allow only some specific amount of water to flow past for any given value of applied pressure. Similarly, only a certain amount of electrical current will flow for a set voltage. In both cases, the degree of opposition offered is inversely proportional to the diameter of the conductor or pipe.

1.5 UNITS OF ELECTRICITY

Electrical current is measured in units called "amperes," often abbreviated simply "amps." One ampere is defined as the passage of a certain quantity of electrical charge past a point in some unit of time—the second. This electrical charge is called the "coulomb" and represents a charge equal to the sum of charges on 6.28×10^{18} electrons. One ampere, then, is the flow of one coulomb of charge per second, or

$$I = \frac{Q}{t} \tag{1-2}$$

where I is the current in amperes.
Q is the electrical charge in coulombs.
t is time in seconds.

(Note that the electrical charge on a single electron is equal to 1.6×10^{-19} coulomb.)

The ampere has a magnitude that is quite suitable for many practical applications, but may be too unwieldy in others. Smaller units are often required, so we also must use the *milli*ampere and the *micro*ampere. The milliampere (mA) is equal to 10^{-3} (that is 0.001) ampere, while the microampere (μA) is equal to 10^{-6} (0.000001) ampere. Figure 1.7 gives some of the more common prefixes used in conjunction with basic electrical units.

The unit of electrical resistance is the "ohm." One ohm can be defined as the resistance of a column of mercury (or some other material) with specific dimensions, but for our purposes we shall use the old definition: One ohm is the resistance that will allow the passage of one ampere of current when a potential of one volt is applied.

(Prefix)-Units	*Multiply Units by:*
Giga–	1,000,000,000 (10^9)
Mega–	1,000,000 (10^6)
Kilo–	1,000 (10^3)
Milli–	.001 (10^{-3})
Micro–	.000001 (10^{-6})
Pico–	.000000001 (10^{-9})

Example. .000001 ampere equals 1 "μA" or microampere

Figure 1.7 Metric prefixes for electrical units.

1.6 OHM'S LAW

Ohm's law describes the relationship between the three basic electrical parameters: voltage, current, and resistance. Stated as a formula that you are expected to remember, Ohm's law is given by

$$E = IR \tag{1-3}$$

where E is the electrical potential in volts.
I is the electrical current in amperes.
R is the resistance in ohms.

We can obtain other forms of Ohm's law by doing a little algebra on the basic equation. These are

$$I = \frac{E}{R} \qquad R = \frac{E}{I} \tag{1-4}$$

"Conductance" is another electrical parameter that is seen occasionally. It is merely the reciprocal of resistance, and is measured in a unit called the "mho" (which is merely "ohm" spelled backwards). While the resistance is a measure of a circuit's opposition to the flow of current, conductance is a measure of its *ability* to conduct current. Conductance is given by

$$G = \frac{1}{R} \tag{1-5}$$

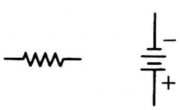
where G is the conductance in mhos.
R is the resistance in ohms.

Ohm's law example. Suppose that an electrical circuit passes a 10-mA (0.01-A) current through a resistance of 1250 Ω. What is the applied voltage?

$$E = I \times R$$
$$E = (0.01)(1250) \tag{1-6}$$
$$E = 12.5 \text{ V}$$

1.7 SIMPLE ELECTRICAL CIRCUITS

Before we can discuss circuits in any detail, there must be established some means for graphic communication. To that end, electronics people use schematic symbols to represent electrical circuitry. Resistors, for example, are represented by Figure 1.8a and batteries by Figure 1.8b.



(a) (b) **Figure 1.8** Schematic symbols for **(a)** resistor, and **(b)** battery.

If no polarity marking is used on the battery symbol, you are usually safe in assuming that the short bar is the negative end of the battery.