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ELECTRONICS

The Easy Way

FOURTH EDITION

Rex Miller

Professor Emeritus, State University College
Buffalo, New York

Mark R. Miller

Chair and Associate Professor, Texas A & M University-Kingsville
Kingsville, Texas



ELECTRONICS

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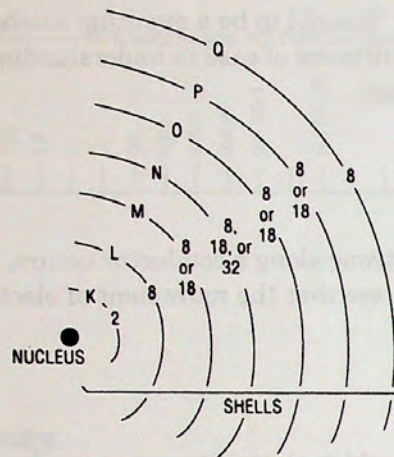


Figure 2-3C. Identification of atomic shells and the number of electrons in each shell.

trons, the greater this tendency. On the other hand, atoms with more than four electrons in their orbits or last shell have a tendency to acquire one or more additional electrons. In elements with atomic valences of four, adjacent atoms form into a *crystal structure* sharing their electrons in *covalent bonds*. Such bonds fill the valence shell, and the material is electrically inert. This creates the *semiconductor properties* that are the basis of solid state (transistor) electronics.

Free Electrons

Electrons in copper drift along in a random fashion when at room temperature.

Heat is only one of the types of energy that can cause electrons to be forced from their orbits. A magnetic field can also be used to cause electrons to move in a given direction. Light energy and pressure on a crystal are also used to generate electricity by forcing electrons to flow along a given path. When electrons leave their orbits, they move from atom to atom at random, drifting in no particular direction. Electrons that move in such a way are referred to as *free electrons*. However, a force can be used to cause them to move in a given direction. That is how electricity (the flow of electrons along a conductor) is generated. A conductor is any material that has many free electrons by virtue of its physical makeup.

Electric Energy

So far you have read about electrons being very small. Just how small are they? Well, electrons are incredibly small. The diameter of an electron is about 0.000 000 000 000 22 (or 2.2×10^{-13}) in. You may wonder how anything so small can be a source of energy. Much of the answer lies in the fact that electrons move at nearly the speed of light, or 186,000 miles per second (mi/s). In metric terms that is 300 million meters per second (m/s). As you can see from their size, billions of them can move at once through a wire. The combination of speed and concentration together produces great energy.

As you study more about electricity, electron theory, and electronics, you will discover

that the electron is thought to be a quantum mechanical pattern, rather than a little solid ball. However, for purposes of ease in understanding and definition, we will refer to it here as a *particle of energy*.

Current Flow

When a flow of electrons along a conductor occurs, this is commonly referred to as *current flow*. Thus, you can see that the movement of electrons is related to current electricity.

Conductors

A material through which electricity passes easily is called a *conductor* because it has free electrons. In other words, a conductor offers very little resistance or opposition to the flow of electrons.

All metals are conductors of electricity to some extent. Some are much better than others. Silver, copper, and aluminum let electricity pass easily. Silver is a better conductor than copper. However, copper is used more frequently because it is cheaper. Aluminum is used as a conductor where light weight is important.

Why are some materials good conductors? One of the most important reasons is the presence of *free electrons*. If a material has many electrons which are free to move away from their atoms, that material will be a good conductor of electricity.

Although free electrons usually move in a haphazard way, their movement can be controlled. The electrons can be made to move in the same direction, and this flow is called *electric current*.

Conductors may be in the form of bars, tubes, or sheets. The most familiar conductors are wire. Many sizes of wire are available. Some are only the thickness of a hair. Other wire may be as thick as your arm. To prevent conductors from touching at the wrong place they are usually coated with a plastic or cloth material. This covering on the conductor is called an *insulator*.

Insulators

An insulator is a material with very few, if any, free electrons. No known material is a perfect insulator. However, there are materials that are such poor conductors that they are classified as insulators. Glass, dry wood, rubber, mica, and certain plastics are insulating materials.

Semiconductors

So far you have looked at insulators and conductors. In between the two extremes are semiconductors. Semiconductors in the form of transistors, diodes, and integrated circuits or chips are used every day in electronic devices. Now is the time to place them in their proper category.

Materials used in the manufacture of transistors and diodes have a conductivity halfway between that of a good conductor and a good insulator. Therefore, the name *semi-*

1 Os

Con:
Feec
Osci
Crys
Tra:
New
Mic
Sun
Rev

12 M

D

Mo:
AM
Am
Fre
Phi
Del
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Otl
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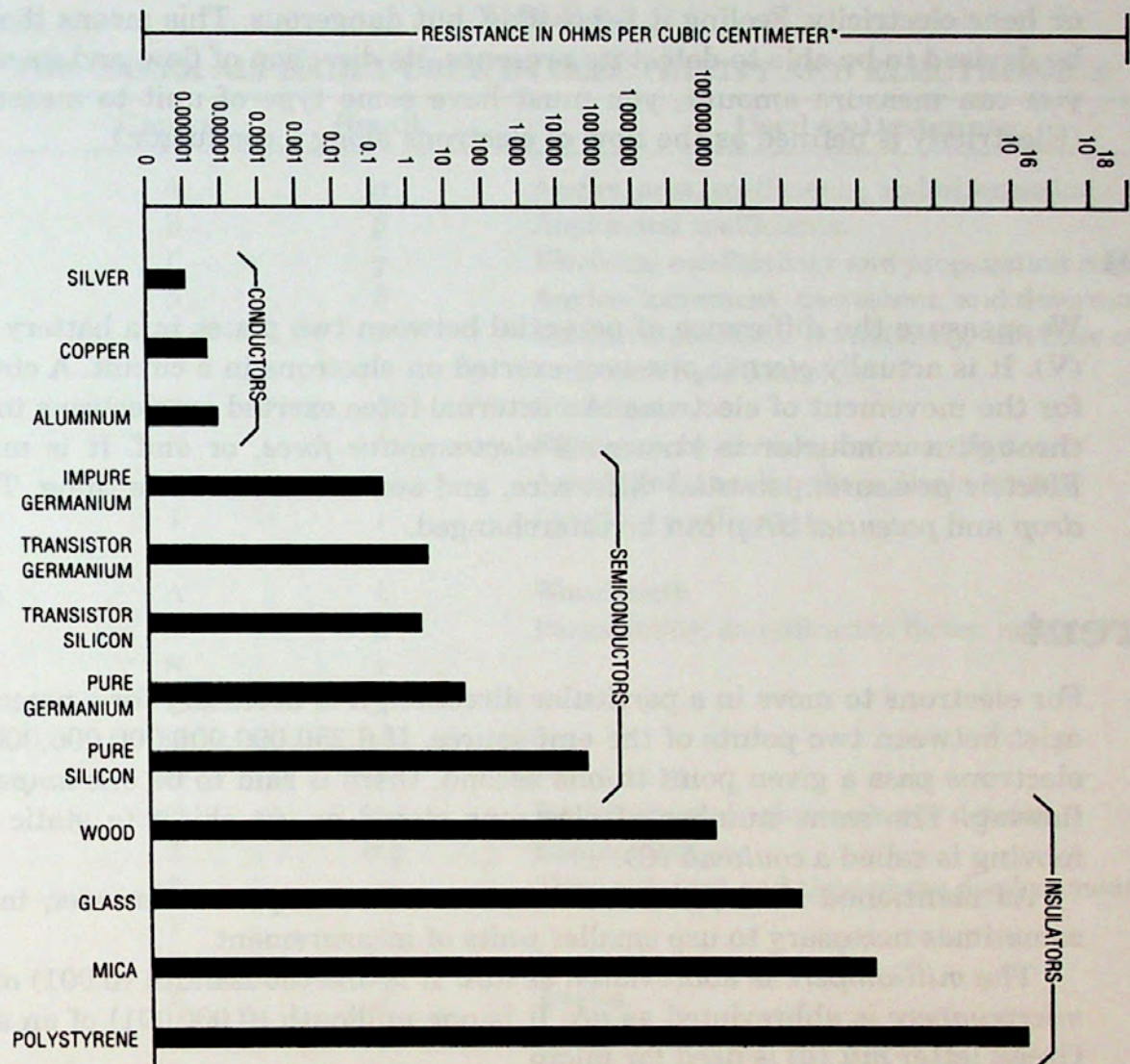


Figure 2-4. Location of insulators, semiconductors, and conductors in relation to one another in terms of inherent resistance.

*A cubic centimeter (cm^3) is one centimeter (0.3937 inches) long, one centimeter wide, and one centimeter high.

conductor is given them. Germanium and silicon are the two most commonly known semiconductor materials. Through the introduction of small amounts of other elements (called impurities) these nearly pure (99.999999%) elements become *limited* conductors. The opposite of conductors is resistors. *Resistors* are devices used to give a measured amount of opposition or resistance to the flow of electrons. This opposition to current flow is measured in ohms (Ω) and indicates the amount of resistance a piece of material offers to the flow of electrons. Take a look at Figure 2-4 to see how these semiconductor materials are placed between good conductors and poor conductors.

Voltage and Current

In order to be able to measure the movement of electrons along a conductor, it is necessary to have units of measurement. This is somewhat difficult since you cannot see, taste, smell,

or hear electricity. Feeling it is possible, but dangerous. This means that some way must be devised to be able to detect its presence, its direction of flow, and its magnitude. Before you can measure amount, you must have some type of unit to measure electricity in. (Electricity is defined as the flow of electrons along a conductor.)

Volts

We measure the difference of potential between two plates in a battery in terms of volts (V). It is actually *electric pressure* exerted on electrons in a circuit. A circuit is a pathway for the movement of electrons. An external force exerted on electrons to make them flow through a conductor is known as *electromotive force*, or emf. It is measured in volts. Electric pressure, potential difference, and emf mean the same thing. The words *voltage drop* and *potential drop* can be interchanged.

Current

For electrons to move in a particular direction, it is necessary for a potential difference to exist between two points of the emf source. If 6,250,000,000,000,000,000 (or 6.25×10^{18}) electrons pass a given point in one second, there is said to be one *ampere* (A) of current flowing. The same number of electrons stored on an object (a static charge) and not moving is called a *coulomb* (C).

As mentioned above, current is measured in amperes. However, in electronics it is sometimes necessary to use smaller units of measurement.

The *milliampere* is abbreviated as mA. It is one-thousandth (0.001) of an ampere. The *microampere* is abbreviated as μA . It is one-millionth (0.000 001) of an ampere. Note the Greek letter *mu* (μ) is used for micro.

You may want to become familiar with the Greek alphabet. Table 2-1 defines the terms used in electricity and electronics and their corresponding Greek letters.

Current flow is assumed to be from negative (–) to positive (+) in our explanations here. Electron flow is negative (–) to positive (+), and we assume that current flow and electron flow are one and the same. It makes explanations simpler as we progress into electronics. The *conventional* current flow is the opposite, or positive (+) to negative (–).

An ammeter is used to measure current flow in a circuit. A milliammeter is used to measure smaller amounts, while the microammeter is used to measure very small amounts of current. (See Table 2-2 for metric prefixes.)

A voltmeter is used to measure voltage. In some instances it is possible to obtain a meter which will measure both voltage and current plus resistance. This is called a *multi-meter*, or *volt-ohm-milliammeter* (VOM).

Power

Power is defined as the *rate* at which work is done. It is expressed in metric measurement terms of watts (W) for power and joules (J) for energy or work. A *watt* is the power that gives rise to the production of energy at the rate of one joule per second ($W = J/s$). A *joule*

TABLE 2-1
THE GREEK ALPHABET USED IN ELECTRICITY AND ELECTRONICS

Name	Capital	Small	Used to Designate
Alpha	A	α	Angles, area, coefficients, and attenuation constant.
Beta	B	β	Angles and coefficients.
Gamma	Γ	γ	Electrical conductivity and propagation constant.
Delta	Δ	δ	Angles, increment, decrement, and determinants.
Epsilon	E	ϵ	Dielectric constant, permittivity, and base of natural logarithms.
Zeta	Z	ζ	Coordinates.
Eta	H	η	Efficiency, hysteresis, and coordinates.
Theta	Θ	$\nu \theta$	Angles and angular phase displacement.
Iota	I	ι	Coupling coefficient.
Kappa	K	κ	
Lambda	Λ	λ	Wavelength.
Mu	M	μ	Permeability, amplification factor, and prefix <i>micro</i> .
Nu	N	ν	
Xi	Ξ	ξ	
Omicron	O	o	
Pi	Π	π	Pi = 3.1416.
Rho	P	ρ	Resistivity and volume charge density.
Sigma	Σ	$\sigma \varsigma$	Summation.
Tau	T	τ	Time constant and time-phase displacement.
Upsilon	Y	υ	
Phi	Φ	$\phi \varphi$	Magnetic flux and angles.
Chi	X	χ	Angles.
Psi	Ψ	ψ	Dielectric flux.
Omega	Ω	ω	Resistance in ohms and angular velocity.

is the work done when the point of application of force of one newton is displaced a distance of one meter in the direction of the force ($J = N \cdot m$).

It has long been the practice in this country to measure work in terms of horsepower (hp). Electric motors are still rated in horsepower and probably will be for some time inasmuch as the United States did not adopt the metric standards for everything.

Power can be electric or mechanical. When a mechanical force is used to lift a weight, *work* is done. The rate at which the weight is moved is *power*. *Horsepower* is defined in terms of moving a certain weight over a certain distance in one minute (e.g., 33,000 lb lifted 1 ft in 1 min equals 1 hp). Energy is consumed in moving a weight or when work is done. The findings in this field have been equated with the same amount of work done by electric energy. It takes 746 W of electric power to equal 1 hp.

The horsepower rating of electric motors is arrived at by taking the voltage and multiplying it by the current drawn under full load. This power is measured in watts. In other words, 1 V times 1 A equals 1 W. When put into a formula it reads:

$$\text{Power} = \text{volts} \times \text{amperes} \quad \text{or} \quad P = E \times I$$

where E = voltage, or emf, and I = current, or intensity of electron flow.

TABLE 2-2

METRIC PREFIXES AND POWERS OF TEN

Metric Prefixes

Multiple	Prefix	Abbrev.	Multiple	Prefix	Abbrev.
10^{12}	tera	T	10^{-1}	deci	d
10^9	giga	G	10^{-2}	centi	c
10^6	mega	M	10^{-3}	milli	m
10^4	myria	My	10^{-6}	micro	μ
10^3	kilo	k	10^{-9}	nano	n
10	deka	D	10^{-12}	pico	p

$1 = 10^0$

$10 = 10^1$

$100 = 10^2$

$1\,000 = 10^3$

$10\,000 = 10^4$

$100\,000 = 10^5$

$1\,000\,000 = 10^6$

Likewise, powers of ten can be used to simplify decimal expressions. The submultiples of 10 from 0.1 to 0.000001, with their equivalents in powers of ten, are:

$0.1 = 10^{-1}$

$0.01 = 10^{-2}$

$0.001 = 10^{-3}$

$0.000\,1 = 10^{-4}$

$0.000\,01 = 10^{-5}$

$0.000\,001 = 10^{-6}$

Scientific Notation (Powers of Ten)

Large numbers can be simplified by using scientific notation (powers of ten). For example, the multiples of 10 from 1 to 1,000,000, with their equivalents in powers of ten, are:

Kilowatt. The kilowatt is commonly used to express the amount of electric energy used or available. The term *kilo* (k) means one thousand (1000). A kilowatt (kW) is one thousand watts.

When the kilowatt is used in terms of power dissipated or consumed by a home for a month, it is expressed in kilowatthours. The unit kilowatthour is abbreviated as kWh. It is the equivalent of one thousand watts used for a period of one hour. Electric bills are figured or computed on an hourly basis and then read in the kWh unit. The entire month's time is equated to one hour's time.

Milliwatt is a term you will encounter when working with electronics. The *milliwatt* (mW) means one-thousandth (0.001) of a watt. The milliwatt is used in terms of some very small amplifiers and other electronic devices. For instance, a speaker used on a portable transistor radio will be rated as 100 milliwatts, or 0.1 W. Transistor circuits are designed in milliwatts, but power line electric power is measured in kilowatts. Keep in mind that *kilo* means 1000 and *milli* means 0.001.

Resistance

Any time there is movement there is resistance. This resistance is useful in electric and electronic circuits. Resistance makes it possible to generate heat, control electron flow, and supply the correct voltage to a device.

Resistance in a conductor depends on four factors: material, length, cross-sectional area, and temperature.

Material. Some materials offer more resistance than others. It depends upon the number of free electrons present in the material.

Length. The longer the wire or conductor, the more resistance it has. Resistance is said to vary *directly* with the length of the wire.

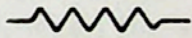
Cross-Sectional Area. Resistance varies inversely with the size of the conductor in cross section. In other words, the larger the wire, the smaller the resistance per foot of length.

Temperature. For most materials, the higher the temperature, the higher the resistance. However, there are some exceptions to this in devices known as *thermistors*. Thermistors change resistance with temperature. They *decrease* in resistance with an increase in temperature. Thermistors are used in certain types of meters to measure temperature.

Resistance is measured by a unit called the *ohm*. The Greek letter omega (Ω) is used as the symbol for electrical resistance.

Resistors

Resistors are devices that provide measured amounts of resistance. They are valuable when it comes to making sure that the proper amount of voltage is present in a circuit. They are useful when generating heat.

Resistors are classified as either *wirewound* or *carbon-composition*. The symbol for a resistor of either type is 

Wirewound resistors are used to provide sufficient opposition to current flow to dissipate power of 5 W or more. A watt is a unit of electric power. A watt is equal to one volt times one ampere.

Wirewound resistors are made of wire that has controlled resistance per unit length.

Resistance causes a voltage drop across a resistor when current flows through it. The voltage is dropped or dissipated as heat and must be eliminated into the air.

Some variable resistors can be varied but can also be adjusted for a particular setting. Resistors are available in various sizes, shapes, and wattage ratings.

Carbon-composition resistors are usually found in electronics devices. They are of low wattage. They are made in $\frac{1}{8}$ -W, $\frac{1}{4}$ -W, $\frac{1}{2}$ -W, 1-W, and 2-W sizes. The physical size determines the wattage rating or their ability to dissipate heat (see Figure 2-5).

Carbon-composition resistors are usually marked according to their ohmic value with a *color code*. The colors are placed on the resistors in rings (see Figure 2-6).

Table 2-3 shows the values for reading the color code of carbon-composition resistors.

Take a close look at a carbon-composition resistor. The bands should be to your left. Read from left to right. The band closest to one end is placed to the left so you can read it from left to right. The first band gives the first number according to the color code. In this case (Figure 2-6) it is red, or 2. The second band gives the next number, which is violet, or 7. The third band represents the multiplier or divisor.

If the third band is a color in the 0 to 9 range in the color code, it states the number of zeros to be added to the first two numbers. Orange is 3; so the resistor in Figure 2-6 has a value of 27,000 Ω of resistance.

The 27,000 Ω is usually written as 27 k Ω . The k stands for thousand; it takes the place of three zeros. In some cases, resistors are referred to as 27 M Ω (which means 27,000,000, or 27 million Ω), because the M stands for *mega*, and that is the unit for million.

If there is no fourth band, the resistor has a tolerance rating of $\pm 20\%$ ($\pm$ means plus or minus). If the fourth band is silver, the resistor has a tolerance of $\pm 10\%$. If the fourth band is gold, the resistor has a tolerance of $\pm 5\%$.

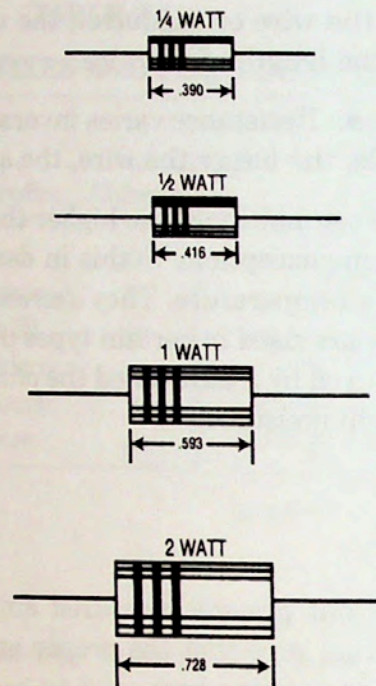


Figure 2-5. Wattage ratings of carbon-composition resistors. All measurements shown here are in inches.

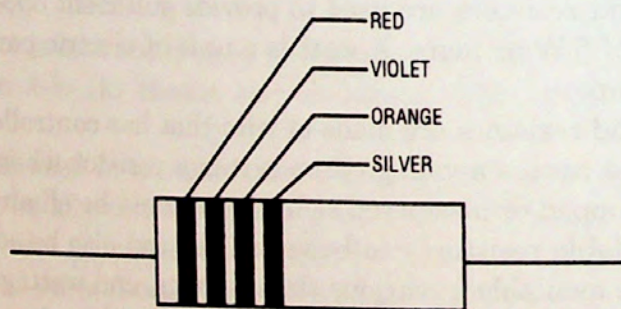


Figure 2-6. A 27,000-ohm (Ω) resistor.

TABLE 2-3

RESISTOR COLOR CODE

0 Black	5 Green
1 Brown	6 Blue
2 Red	7 Violet
3 Orange	8 Gray
4 Yellow	9 White

Silver and gold may also be used for the *third* band. In this case, according to the color code, the first two numbers (obtained from the first two color bands) must be divided by 10 or 100. Silver means divide the first two numbers by 100. Gold means divide the first two numbers by 10. For example, if the bands of the resistor are red, yellow, and gold, then the value is 24 divided by 10, or 2.4 Ω . If the third band is silver and the two colors are yellow and orange, then the 43 is divided by 100 to produce the answer of 0.43 Ω . Keep in mind, though, that the fourth band will still be either gold or silver to indicate the tolerance.

Resistors marked with the color code are available in hundreds of size and wattage rating combinations. Wattage rating refers to the wattage or power consumed by the resistor.

Ohm's Law

A German physicist by the name of Georg Ohm discovered the relationship between voltage, current, and resistance in 1827. He found that in any circuit where the only opposition to the flow of electrons is resistance, there is a relationship between the values of voltage, current, and resistance. The strength or intensity of the current is directly proportional to the voltage and inversely proportional to the resistance.

It is easier to work with Ohm's law when it is expressed in a formula. In the formula, E represents emf, or voltage; I is the current, or the intensity of electron flow; R stands for resistance. The formula is $E = I \times R$. It is used to find the emf (voltage) when the current and the resistance are known.

To find the current, when the voltage and resistance are known, use

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

To find the resistance, when the voltage and current are known, use

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

Using Ohm's Law

Ohm's law is very useful in electrical and electronics work. You will need it often to determine the missing value. In order to make it easy to remember the formula take a look at Figure 2-7. Here the formulas are arrived at by placing your finger on the unknown and the other two will have their relationship displayed.

The best way to become accustomed to solving problems is to start with something simple, such as:

1. If the voltage is given as 100 V and the resistance is 25 Ω , it is a simple problem and a practical application of Ohm's law to find the current in the circuit. Use

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

Substituting the values in the formula,

$$I = \frac{100}{25}$$

means 100 is divided by 25 to produce 4 A for the current.

2. If the current is given as 2 A (you may read it on an ammeter in the circuit), and the voltage (read from the voltmeter) is 100 V, it is easy to find the resistance. Use

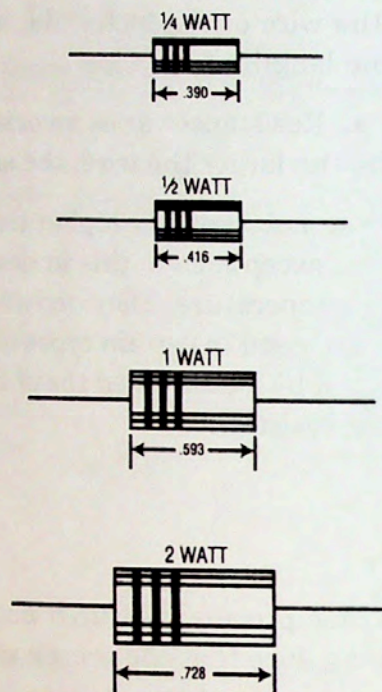


Figure 2-5. Wattage ratings of carbon-composition resistors. All measurements shown here are in inches.

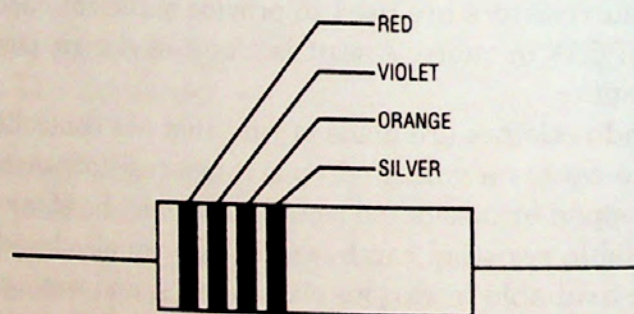


Figure 2-6. A 27,000-ohm (Ω) resistor.

TABLE 2-3

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0 Black	5 Green
1 Brown	6 Blue
2 Red	7 Violet
3 Orange	8 Gray
4 Yellow	9 White

Silver and gold may also be used for the *third* band. In this case, according to the color code, the first two numbers (obtained from the first two color bands) must be divided by 10 or 100. Silver means divide the first two numbers by 100. Gold means divide the first two numbers by 10. For example, if the bands of the resistor are red, yellow, and gold, then the value is 24 divided by 10, or 2.4 Ω . If the third band is silver and the two colors are yellow and orange, then the 43 is divided by 100 to produce the answer of 0.43 Ω . Keep in mind, though, that the fourth band will still be either gold or silver to indicate the tolerance.

Resistors marked with the color code are available in hundreds of size and wattage rating combinations. Wattage rating refers to the wattage or power consumed by the resistor.

Ohm's Law

A German physicist by the name of Georg Ohm discovered the relationship between voltage, current, and resistance in 1827. He found that in any circuit where the only opposition to the flow of electrons is resistance, there is a relationship between the values of voltage, current, and resistance. The strength or intensity of the current is directly proportional to the voltage and inversely proportional to the resistance.

It is easier to work with Ohm's law when it is expressed in a formula. In the formula, E represents emf, or voltage; I is the current, or the intensity of electron flow; R stands for resistance. The formula is $E = I \times R$. It is used to find the emf (voltage) when the current and the resistance are known.

To find the current, when the voltage and resistance are known, use

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

To find the resistance, when the voltage and current are known, use

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

Using Ohm's Law

Ohm's law is very useful in electrical and electronics work. You will need it often to determine the missing value. In order to make it easy to remember the formula take a look at Figure 2-7. Here the formulas are arrived at by placing your finger on the unknown and the other two will have their relationship displayed.

The best way to become accustomed to solving problems is to start with something simple, such as:

1. If the voltage is given as 100 V and the resistance is 25 Ω , it is a simple problem and a practical application of Ohm's law to find the current in the circuit. Use

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

Substituting the values in the formula,

$$I = \frac{100}{25}$$

means 100 is divided by 25 to produce 4 A for the current.

2. If the current is given as 2 A (you may read it on an ammeter in the circuit), and the voltage (read from the voltmeter) is 100 V, it is easy to find the resistance. Use

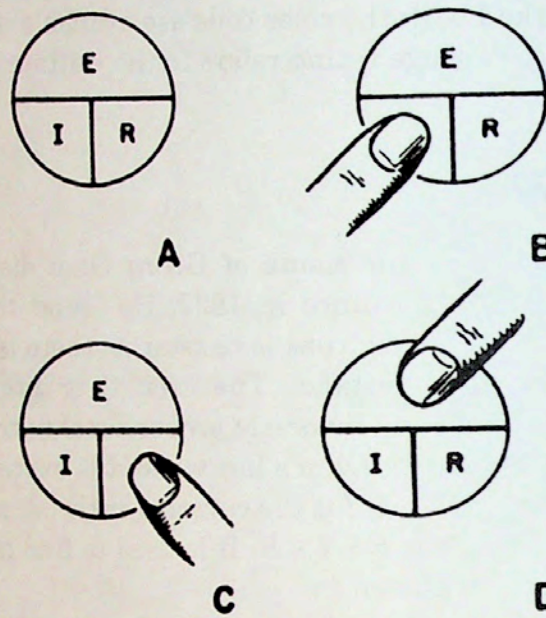


Figure 2-7. Ohm's law. Place your finger on the unknown value and the remaining two letters will give the formula to use for finding the unknown value.

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

Substituting the values in the formula,

$$R = \frac{100}{2}$$

means 100 divided by 2 equals 50 Ω for the circuit.

3. If the current is known to be 10 A, and the resistance is found to be 50 Ω (measured before the circuit is energized), it is then possible to determine how much voltage is needed to cause the circuit to function properly. Use

$$E = I \times R$$

Substituting the values in the formula,

$$E = 10 \times 50$$

means 10 times 50 produces 500 or that it would take 500 V to push 10 A through 50 Ω of resistance.

Circuits

There are a number of different types of circuits. Circuits are the pathways along which electrons move to produce various effects.

The *complete* circuit is necessary for the controlled flow or movement of electrons along a conductor (see Figure 2-8). A complete circuit is made up of a source of electricity, a conductor, and a consuming device. This is the simplest of circuits. The flow of electrons through the consuming device produces heat, light, or work.

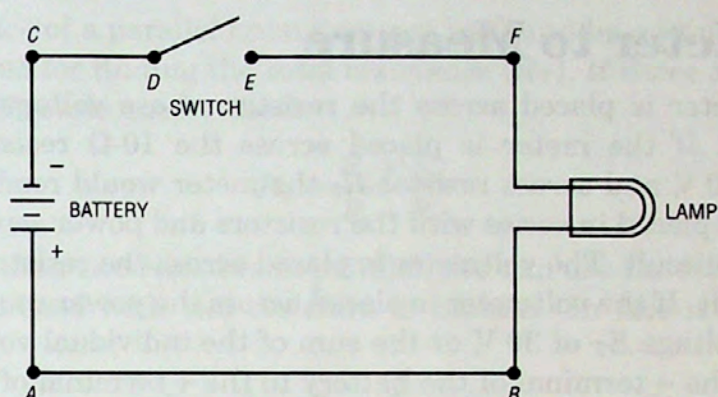


Figure 2-8. A simple circuit with a switch.

In order to form a complete circuit, these rules must be followed:

1. Connect one side of the power source to one side of the consuming device: A to B. (See Figure 2-8.)
2. Connect the other side of the power source to one side of the control device, usually a switch: C to D. (See Figure 2-8.)
3. Connect the other side of the switch to the consuming device it is supposed to control: E to F. (See Figure 2-8.) When the switch is closed the circuit is complete.

However, when the switch is open, or not closed, there is no path for electrons to flow, and there is an *open circuit* condition where no current flows.

This method is used to make a complete path for electrons to flow from that side of the battery with an excess of electrons to the other side which has a deficiency of electrons. The battery has a negative (–) charge where there is an excess of electrons and a positive (+) charge where there is a deficiency of electrons. Yes, you read it right: the – means excess and + means deficiency. This is due to the fact that we are using the current flow and electron flow as both the same and from – to + in the circuit.

A single path for electrons to flow is called a *closed*, or *complete*, *circuit*. However, in some instances the circuit may have more than one consuming device. In this situation we have what is called a *series circuit* if the two or more resistors or consuming devices are placed one after the other as shown in Figure 2-9.

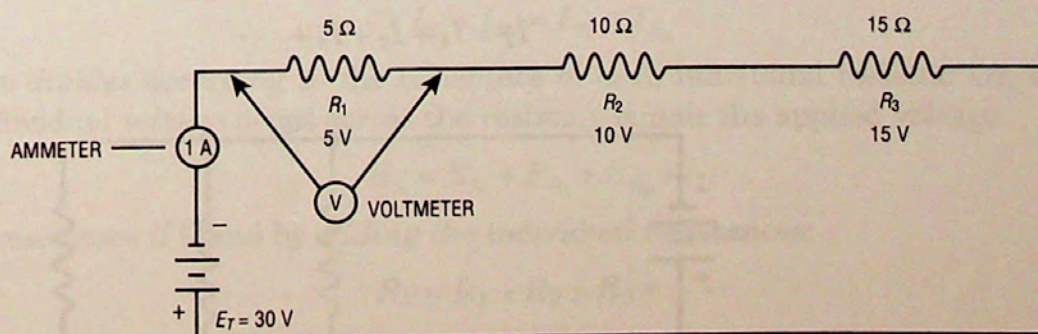


Figure 2-9. A series circuit with three resistors.

Using the Meter to Measure

The voltmeter is placed across the resistor whose voltage drop is being measured. See Figure 2-9. If the meter is placed across the $10\text{-}\Omega$ resistor R_2 , the voltage indicated would be 10 V, and across resistor R_3 the meter would read 15 V. Note, however, that the ammeter is placed in series with the resistors and power source. The ammeter can become part of the circuit. The voltmeter is placed across the resistor and is not a permanent part of the circuit. If the voltmeter is placed across the power source (the battery) it would read the total voltage E_T of 30 V, or the sum of the individual voltage drops around the circuit loop from the - terminal of the battery to the + terminal of the battery. See the following discussion of the series circuit.

Series Circuit

Figure 2-9 shows a series circuit. The three resistors are connected in series, or one after the other, to complete the path from one terminal of the battery to the other. The current flows through each of them before returning to the positive terminal of the battery.

There is a law concerning the voltages in a series circuit. *Kirchhoff's voltage law* states that the sum of all voltages across resistors or loads is equal to the applied voltage. Voltage drop is considered across the resistor. Figure 2-9 shows the current flow through three resistors. The voltage drop across R_1 is 5 V. Across R_2 the voltage drop is 10 V. And, across R_3 the voltage drop is 15 V. The sum of the individual voltage drops is equal to the total or applied voltage of 30 V. E_T means total voltage. It may also be written as E_A for applied voltage or E_S for source voltage.

To find the total resistance in a series circuit, just add the individual resistances or $R_T = R_1 + R_2 + R_3$. In this instance (Figure 2-9) the total resistance is $5 + 10 + 15$, or $30\text{ }\Omega$.

Parallel Circuits

In a parallel circuit each resistance is connected directly across the voltage source or line. There are as many separate paths for current flow as there are branches (see Figure 2-10).

The voltage across all branches of a parallel circuit is the same. This is because all branches are connected across the voltage source. Current in a parallel circuit depends on the resistance of the branch. Ohm's law can be used to determine the current in each branch. You can find the total current for a parallel circuit by simply adding the individual currents. When written as a formula it reads

$$I_T = I_1 + I_2 + I_3 + \dots$$

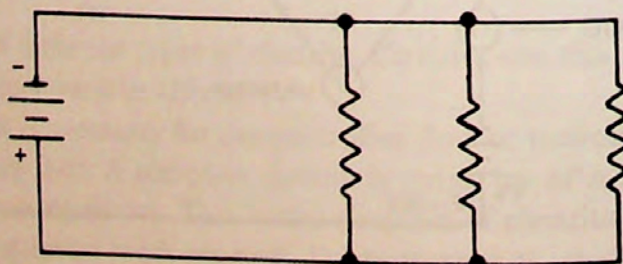


Figure 2-10. A parallel circuit.

The total resistance of a parallel circuit cannot be found by adding the resistor values. Two formulas are used for finding the total resistance (R_T). If there are *only two* resistors in parallel, a simple formula can be used:

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

If there are more than two resistors in parallel, you can use the following formula. This formula may also be used with two resistors in parallel. In fact it can be used for *any* number of resistors.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \dots$$

One thing should be kept in mind in parallel resistances: The total resistance is always less than the smallest resistance.*

As branches are added to a parallel circuit, the voltage across each branch is the same. However, the current divides according to the resistance in the branch. The total current is equal to the sum of the individual currents. Inasmuch as current and resistance are inversely related, that means if the currents are added then the total or equivalent resistance of the parallel circuit decreases with the increase in current. In order to account for this decrease even though more resistance is added to the circuit, the mathematical answer lies in the reciprocal ($1/R$) formula. The reciprocal of the sum of the reciprocals of the individual resistors in the circuit produces the desired mathematical result and Ohm's law is satisfied when applied to the total circuit values and when used for individual values within the branch circuits.

Using Ohm's Law to Solve Circuit Problems

Examples of problem solving for series circuits using Ohm's law will show how the circuits use the various physical laws of nature.

Keep in mind that in a series circuit three rules aid in the solution of these circuit problems. They deal with the three factors found in any circuit — voltage, current, and resistance.

Rules of Series Circuits

1. Current in all resistors is the *same* as the total current.

$$I_T = I_{R_1} = I_{R_2} = I_{R_3}$$

2. Voltage *divides* according to the resistance of each individual resistor. Or, the sum of the individual voltage drops across the resistors equals the applied voltage.

$$E_A = E_{R_1} + E_{R_2} + E_{R_3} + \dots$$

3. Total resistance is found by *adding* the individual resistances:

$$R_T = R_1 + R_2 + R_3 + \dots$$

*This is not true if one of the resistances is *negative*. The condition occurs only in active circuits, so for most applications the statement is true enough to be used for quick checks of your math.

Example 1

What is the total resistance of four resistors connected in series if the resistors have resistances of 10, 20, 30, and 40 Ω ?

1. Determine what is to be found. In this case it is the total resistance.
2. Note that the formula for finding total resistance in a series circuit is

$$R_T = R_1 + R_2 + R_3 + R_4$$

3. Substitute the resistances for the letters:

$$R_T = 10 + 20 + 30 + 40$$

4. Sum up the resistances to produce 100 Ω .

Keep in mind that voltage drop refers to the voltage *across* an individual resistor.

Example 2

What is the total resistance of the circuit shown in Figure 2-11?

1. Determine what is to be found. In this case it is the total resistance.
2. Note that the formula for finding the total resistance in a series circuit is

$$R_T = R_1 + R_2 + R_3$$

3. Substitute the resistances for the letters in the formula:

$$R_T = 20 + 30 + 50$$

4. Sum up the resistances to produce 100 Ω .

Using Ohm's law, it is possible to determine the voltage drop across each resistor if the total current is given.

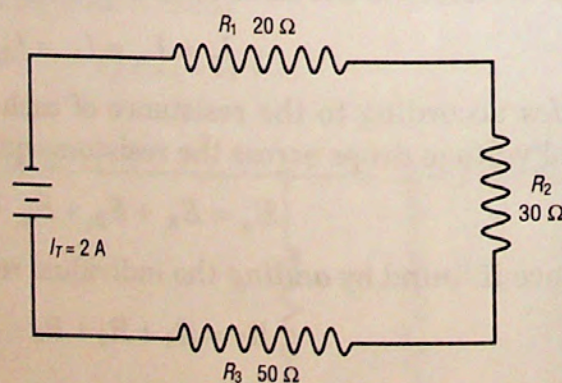


Figure 2-11.

Example 3

What is the voltage drop across each resistor in Figure 2-11 if the total current is 2 amperes?

1. Determine what you know at this point. Check the circuit to see what the resistor values are: They are 20, 30, and 50 Ω .
2. Check what the current is. Current is given at 2 amperes total.
3. Check the rules for the series circuit for current. The total current is equal to the current through each resistor in series, which means that the current through each resistor is 2 amperes.
4. Therefore, you know the current through each resistor, and you know the resistance. The formula (Ohm's law) for finding the voltage drop across each resistor is simply $E = I \times R$.

So,

$$\begin{array}{lll} E_{R_1} = I \times R_1 & \text{or} & E_{R_1} = 2 \times 20 \text{ or } 40 \text{ V} \\ E_{R_2} = I \times R_2 & \text{or} & E_{R_2} = 2 \times 30 \text{ or } 60 \text{ V} \\ E_{R_3} = I \times R_3 & \text{or} & E_{R_3} = 2 \times 50 \text{ or } 100 \text{ V} \end{array}$$

Series-Parallel Circuits

The series-parallel circuit is a combination of the series and the parallel arrangement. Figure 2-12 shows an example of the series-parallel circuit. It takes a minimum of three resistances to make a series-parallel circuit. This type has to be reduced to a series equivalent before it can be solved in terms of resistance. The parallel portions are reduced to the total for that part of the circuit, and then the equivalent resistance is added to the series part to obtain the total resistance.

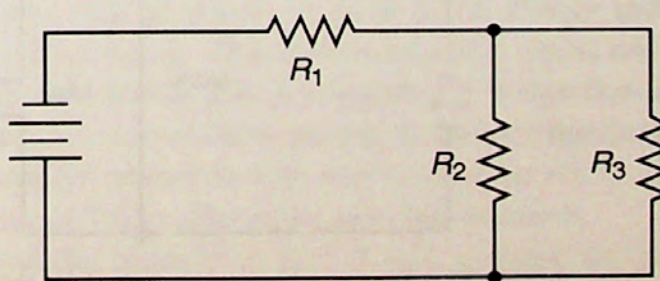


Figure 2-12. A series-parallel circuit.

Total current flows through the first series resistor but divides according to the branch resistances after that. There are definite relationships which must be explored here before that type of circuit can be fully understood. This will be done in a later part of this book.

Open Circuits

An open circuit is an incomplete circuit. Figure 2-13 shows an open circuit that will become a closed circuit once the switch is closed. A circuit can also become open when one of the

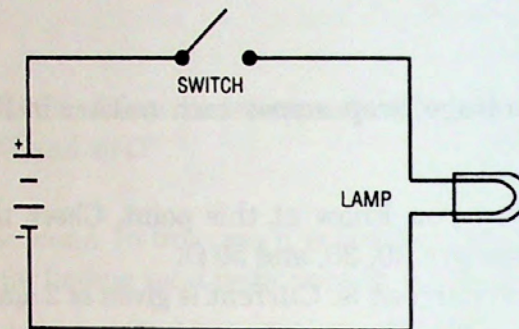


Figure 2-13. An open circuit produced by an open switch.

leads is cut or when one of the terminals has the wire removed. A loose connection can cause an open circuit.

Short Circuits

The short circuit is something to be avoided because it can cause a fire or overheating.

A short circuit has a path of low resistance to electron flow. This is usually created when a low-resistance wire is placed across the consuming device (see Figure 2-14). The greater number of electrons will flow through the path of least resistance rather than through the consuming device. A short usually generates an excess current flow that can result in damage to a number of parts of the circuit. If you wish to prevent the damage caused by short circuits, use a fuse.

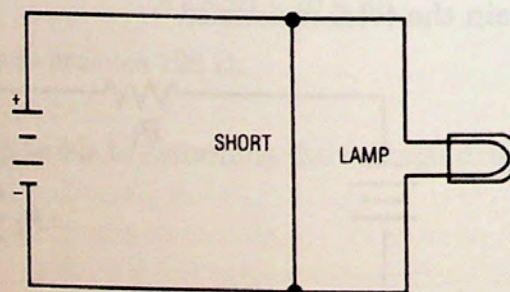


Figure 2-14. A short circuit. The wire has less resistance than the lamp.

Fuses

Fuses are available in a number of sizes and shapes. They are used to prevent the damage done by excess current flowing in a circuit. They are placed in series with the consuming devices. Once too much current flows, it causes the fuse wire inside the fuse case to melt. This opens the circuit and stops the flow of current and prevents the overheating that occurs when too much current is present in a circuit.

The symbol for a fuse is . It fits into a circuit as shown in Figure 2-15.

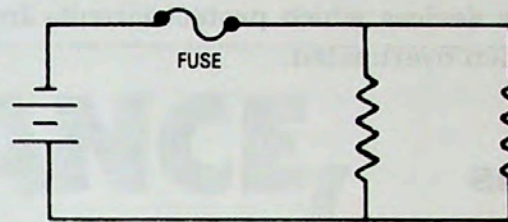


Figure 2-15. The location of the fuse in a circuit.

Summary

Electricity is defined as the flow of electrons along a conductor. Electrons are the smallest part of an atom. An atom is the smallest part of an element which contains all its properties. Electrons can be directed along a given path called a circuit by means of magnetism, heat, light, or pressure. Electrons that move in a random motion are called free electrons. These free electrons when directed in a given direction make up what is called electricity.

Current flow is the flow of electrons along a conductor. Current flow is from negative to positive.

A material through which electricity passes easily is called a conductor. An insulator is a material with very few, if any, free electrons. No known materials are perfect insulators.

The diameter of an electron is about 0.000 000 000 000 22 (or 2.2×10^{-13}) in. Materials used in the manufacture of transistors and diodes have a conductivity between that of a good conductor and a good insulator.

Electricity is measured in terms of volts, amps, and ohms. Meters are used to measure the flow of electrons, the voltage drop across resistors, and the opposition put up to the flow of electrons by certain materials.

Resistance is the opposition to the movement of electrons. Resistance is measured in ohms. Resistors are devices which provide measured amounts of resistance. There are two types of resistors: wirewound and carbon-composition.

Power is defined as the rate at which work is done. Power measured in terms of electrical energy is designated as watts. The watt is one volt times one ampere for one second. The kilowatt is one thousand watts. The kilowatthour is one thousand watts for one hour.

It takes 746 watts to produce one horsepower. It takes a mechanical horsepower defined in terms of 33,000 pounds lifted one foot in one minute to equal one electrical horsepower defined in terms of watts or 746 watts equal one horsepower.

Ohm's law states that the current in any circuit is equal to the voltage divided by the resistance. It can also be substituted so that the voltage is equal to the current times the resistance, or the resistance is equal to the voltage divided by the current.

There are a number of types of circuits. The open circuit does not have a complete path for electron flow from one terminal of the voltage source to the other. A short circuit has a resistance that is too small and therefore takes all the current and bypasses it from the intended load. The series circuit consists of resistors placed end to end. The parallel circuit consists of resistors placed across the power source. The current in a series circuit flows the same through all resistors. The current in a parallel circuit divides according to the branch resistance.

A combination of series and parallel circuits can be made with the use of at least three resistors.

Alternating Current

Most of us have grown up with alternating current (ac). We are used to the 60-hertz (Hz) line current that is furnished to every house in the United States. It is much better than dc when it comes to transporting power over long distances without huge losses. It is also important since electronics relies so heavily on ac. The radio frequencies which bring us radio and television are also ac. In order to get a better understanding of ac, we should look at how it is generated and distributed.

Alternating current was developed by Nicholas Tesla. Its use was introduced around 1900. Niagara Falls, New York, had one of the first commercial ac generators, which was in operation until 1948 when a rock slide ruined it.

Alternating current has a distinct advantage over direct current. Alternating current can be stepped up to obtain higher voltages and lower currents and still produce the same amount of power at the other end of the line. It can be transported over long distances through small wires because of the higher voltages and lower currents. Current determines the size of the wire. Then it is stepped down for local distribution. Since transformers are very efficient machines, very low losses are experienced with ac.

Usually, ac is generated at 13,800 volts (V). This is then stepped up to at least 138,000 V for distribution. The most commonly used high voltages for long-distance transmission are 138,000, 250,000, and 750,000 V. Once the power reaches its destination, it is reduced to as low as 240 V for home use. This is further split for home circuits of 120 V.

Nature of Alternating Current

Alternating current changes its direction of flow as it moves along a wire. It flows in one direction and then the other. Figure 3-5 shows a simple ac generator; Figure 3-6 shows the output of the generator.

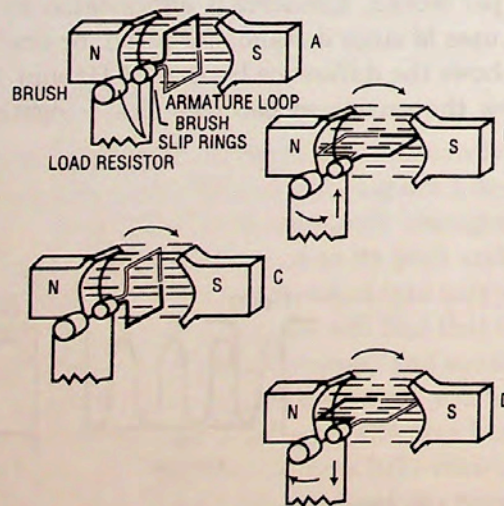


Figure 3-5. Simple ac generator called an alternator.

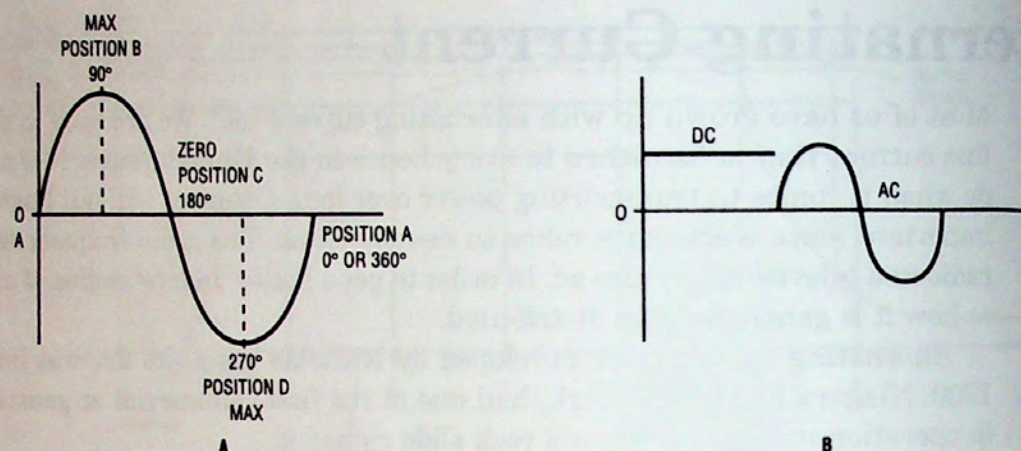


Figure 3-6. A. The sine wave. B. Comparison of ac to dc.

Waveforms

Alternating current is constantly changing. It changes in magnitude and direction. The pattern, or *waveform*, is shown in Figure 3-6. The time base of one second (s) is standard in the electrical field. Whenever you see 60 Hz, you know it means 60 complete sine waves are generated in 1 s.

Frequency

The term *frequency* is used to indicate how many times the alternating current changes direction. The ac you use at home changes direction 60 times per second. This means it moves back and forth 60 times per second. This current is described as having a frequency of 60 Hz. It is said to be 60-Hz ac. Frequency can be expressed in megahertz, or MHz. This is 1 million Hz/s. It can also be expressed in kilohertz, which means 1000 times or hertz per second. Kilohertz is abbreviated as kHz. Note that k is a small letter. However, MHz uses M since it stands for *mega*, or one million.

Figure 3-7 shows the difference between 4 Hz and 1 Hz. Note that both of them occur in 1 s. Note how the waveform becomes closer together as it becomes part of a higher frequency.

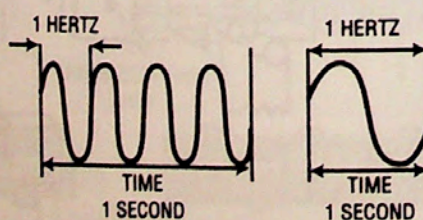


Figure 3-7. 4 Hz and 1 Hz compared.

Maximum and Peak Values of AC

Three values are used to describe ac:

- Peak
- Average
- Root-mean-square (rms)

Peak

The maximum point on a sine wave is the peak value. Both peaks of a single hertz may be included in a reference. If so, it becomes a peak-to-peak value. A peak value of 100 V means that the peak-to-peak value is 200 V (see Figure 3-8).

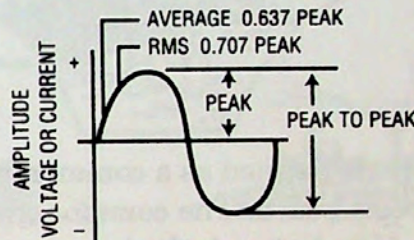


Figure 3-8. Ac sine wave values.

Average

The average of all instantaneous values of a generator is measured at regular intervals. The values are taken at selected points in the generating process. The average of these is the average value of ac current (see Figure 3-8). The average value is 0.637 times the peak. This means that a peak of 100 V is equal to 63.7 V average. However, average is not often used in reference to ac. Instead, root-mean-square (rms) is used more often.

Root-mean-square (rms)

This is a method used for equating ac to dc. Since ac is constantly changing, it forms a sine wave (see Figure 3-6). The values used for rms figuring are taken from selected points in the sine wave generating process. The ac is constantly changing and does not have the heating value of dc. That is because dc comes up to its peak and stays there until turned off. Therefore, if you take the ac sine wave and break it into four parts, each containing 90° of the complete cycle needed to generate 1 Hz, you will find that the instantaneous voltage and current when taken 90 times (once for each degree) and squared, then averaged (*mean* means average) and the square root taken of the average, you will have 0.7071 times the peak value of the sine wave. This shows that rms, effective heat, and heating effect all mean the same thing. You could also get the rms, or 0.7071 value, by taking the *sine* of 45°. Since 45° is one-half of the 90° to the peak of the waveform, it makes more sense mathe-

matically. It also makes sense because the shape of the waveform is not a semicircle, but is shaped more like the mathematical equivalent to a sine value.

Transformers

A practical application of alternating current is its use with the transformer. It has the ability to step up and step down voltages. But, only ac. Direct current does not work with a transformer.

A *transformer* is a device consisting of two coils that can change voltages. The voltage put into a transformer is either stepped up or stepped down. (In some instances, however, isolation transformers are used so that they have the same output as input voltage. They are used to eliminate the ground connection in conventional line current. That way you must come across both terminals to receive a shock instead of any ground and the hot side of the line.)

Ground

A ground in electronics is defined as a common connection such as the chassis or a copper strip on a printed circuit board. The common ground usually has a negative polarity. The chassis of an electrical or electronic device serves as a common return to the power supply and is referred to as the ground. An *earth ground* has a potential of zero. To maintain a good earth ground, a metallic rod 4 to 6 feet long is driven into the ground. Any wire connected to that rod is *grounded*. The power company installs a rod like this when they connect power to your home. The telephone and cable-TV companies wire their network interfaces (lightning protection) to the power company's ground rod. The alternative to earth ground is a *floating ground*. A floating ground is simply a reference point that is not earth grounded. The negative terminal of a car's battery is a floating ground, and any home appliance that has a two-prong electrical plug also has a floating ground. In newer homes a third ground wire is provided for wall outlets for appliances. The symbol for a ground is shown in Figure 3-9.

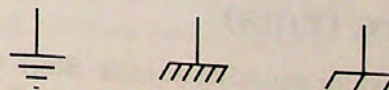


Figure 3-9. Symbols used for a ground or earth.

Types of Transformers

Figure 3-10 shows how transformers are used to distribute electric power from the generator to the consumer. Note that the symbols used for the transformer are two coils of wire with straight lines in between to designate the iron core.

A transformer has a primary winding and a secondary winding. A transformer is simply a coil when it has no load on the secondary. When a load is placed on the output side (the secondary winding), the device actually becomes a transformer.

Desoldering Tool — Usually a vacuum-operated device that lifts molten solder from a terminal or a printed circuit board to aid in the replacement of a defective component.

Dielectric — The insulating material located between the two plates of a capacitor.

Dielectric Constant — A number that indicates the relative quality of dielectric materials. Air is 1, and all other materials are compared with air to produce a constant.

Dielectric Strength — A number expressed in volts per mil. It indicates the breakdown voltage of dielectric materials.

Digitizing — The process of converting analog music or information into digits for use by computers or other digital circuited devices.

Diode — A two-terminal device. The di means two and the ode means electrode. Therefore, it has two electrodes. The diode is used to allow current to flow in only one direction.

DIP — An abbreviation that is used to indicate a type of package used for integrated circuits. It means Dual in-line package.

Direction Current (dc) — Current that flows in only one direction.

Disc — A flat surface used to store data, either electro-magnetically or optically.

Diskette — A flat piece of flexible plastic covered with a magnetic coating that is used to store data (also called a floppy diskette). The existing standard for diskette size is 3.5 inches. Older drives also came in 5.25-inch sizes.

DMM — An abbreviation used to indicate a digital multimeter.

Doping — A process whereby a small amount of impurity is added to a semiconductor material (Germanium or Silicon) to change its properties and cause it to operate as a transistor or diode.

DOS — Disk Operating System. Software that translates the user's commands and allows application programs to interact with the computer's hardware. Supplies a file management system for efficient disk input and output.

Dry Cell — A primary cell that is made up of zinc and carbon with an electrolyte of sal ammoniac. Other types are also available.

Eddy Current — An induced current in the core of a transformer, inductor, or solenoid that is caused by the varying magnetic field produced by alternating current.

Effective Voltage — Another term used to describe an rms voltage. It is 0.7071 times the peak voltage.

EHF — Extremely High Frequency. The frequency range from 30,000 to 300,000 MHz or 30 GHz to 300 GHz.

Electricity — The flow of electrons along a conductor.

Electronic Component — A term that describes an individual part used in electrical or electronic circuits.

Electrolytic Capacitor — A capacitor that has polarity. It has more than 1 microfarad of capacitance and is marked with a + or -. It is made with a paste or liquid dielectric that produces a high capacitance per unit volume.

Electromagnet — A magnet that has a field that is produced by an electric current through a coil of wire.

Electromagnetism — A temporary magnetic field produced by electron flow through a coil of wire.

Electromotive Force (emf) — Another term used for voltage or the force that moves electrons.

Electron — A negatively charged particle of an atom.

Electronics — A term used to describe the physical actions of electrons in devices such as diodes, vacuum tubes, transistors, and integrated circuits.

Electrostatic Field — The energy field surrounding a charged body. The field is represented by lines of force.

Element — A number of definitions can be given. It is a basic substance such as iron or lead. It is also used to describe a part of an electronic device such as the cathode or anode element of a transistor or tube.

Emitter — A terminal of a transistor. It is identified by its characteristic arrow symbol.

Expanded Memory — Memory outside the DOS one-megabyte limit that is accessed in revolving blocks.

Extended Memory — Linear memory extending beyond DOS's one-megabyte limit. Extended memory is only available on 286 and above machines. It is off-limits to XT's.

Facsimile (Fax) — A copy or exact reproduction. A fax machine is a device that can receive over the air or by wire electrical impulses that can be converted into a printed page of text or pictures.

Farad — The unit of measurement for capacitance. The symbol is C. It is abbreviated by F. It is also broken down into microfarads (0.000 001 F) and picofarads (0.000 000 000 001 F).

Feedback — The process of feeding back to the input of a circuit part of its output. Feedback is needed to keep oscillators operating.

FET — An abbreviation for the Field Effect Transistor.

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