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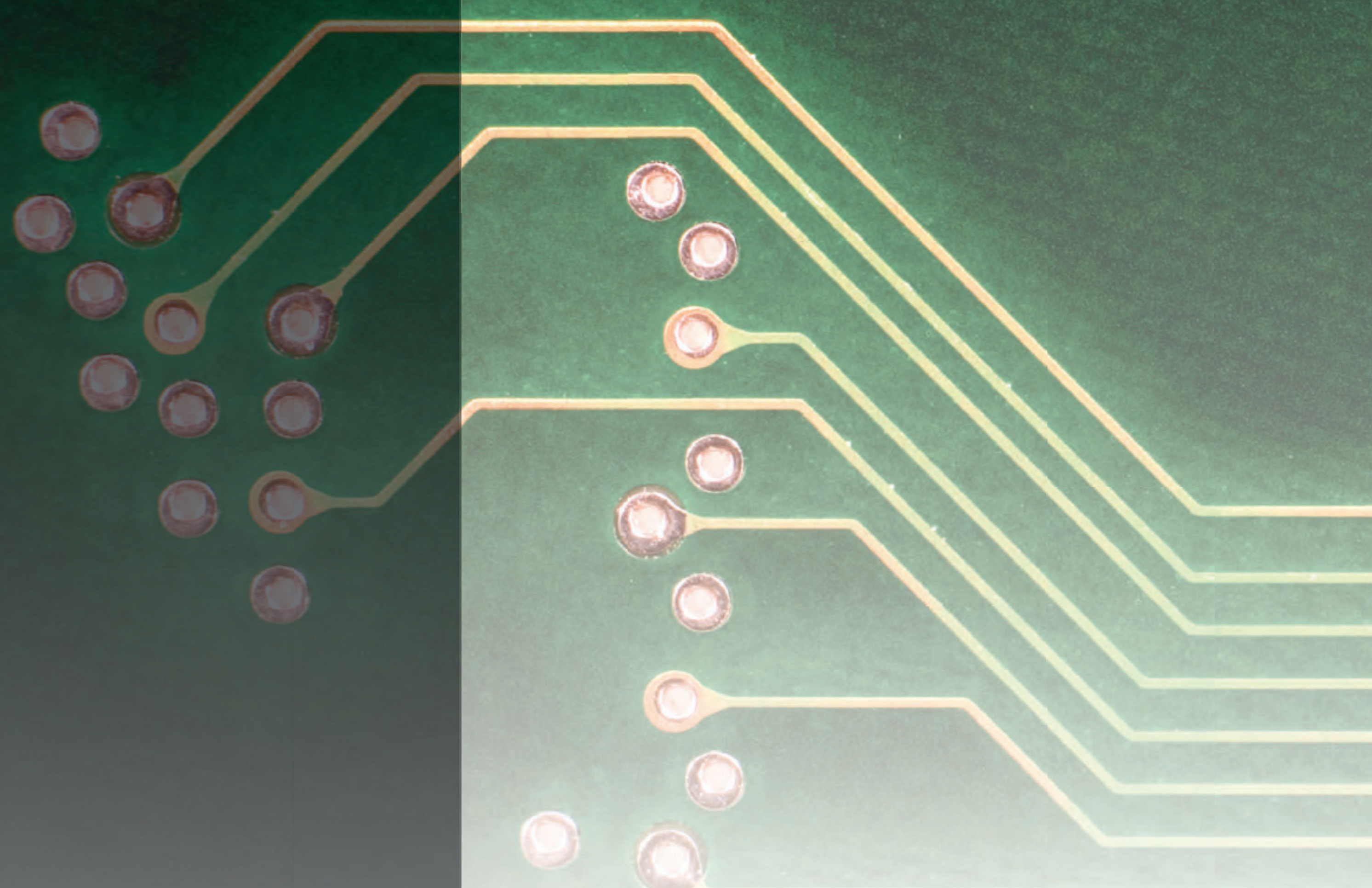
Student Text

Electronics Fundamentals Courseware

Comprehensive Course in AC / DC Electronics

Second Edition



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Chapter 1

Fundamentals of Electricity

Electricity is considered to be the movement of electrons or the flow of current through simple materials and devices. To utilize this current flow it must be controlled.

Electronics is merely a special application of electricity wherein precise manipulation of electrons is employed.

Since electronics is used in conjunction with mechanical systems in modern electronic equipment, the technician must possess a thorough understanding of all facets of electronics. This knowledge would be used during inspection, installation, repair and design.

Atom / Electron Theory

The atom is the basic building block of all matter. It is the smallest piece of an element that still retains all the qualities and the characteristics of a larger piece. There are approximately 100 different kinds of atoms (92 occur in nature, the rest are synthetic).

Atoms carry two opposite charges:

1. Positive-the protons in the nucleus have a positive charge. The atom has a shortage of electrons
2. Negative-the atom has an excess of electrons. The electrons have a negative charge

Atoms are organized into molecules that can be separated into two categories: elements and compounds. An element is when all the atoms are of the same type. A compound is when the atoms are of different elements. Billions of different substances can be formed by various combinations of the basic elements.

Composition Of An Atom

The nucleus is the central core of an atom. The nucleus contains protons that have a positive charge and neutrons that have no charge.

The electron shells are energy levels at certain distances from the nucleus and contains the electrons.

Electrons have a negative charge. Each shell contains a certain amount of electrons. The innermost shells are always filled. The outermost shell gains or loses electrons. When heated, the energy levels expand moving away from the nucleus. This affects the ability of the nucleus to hold electrons. Refer to Figure 1-1.

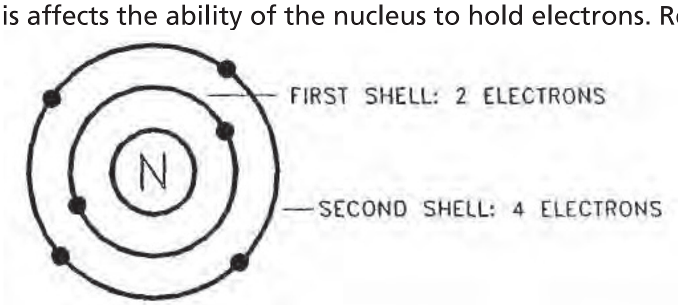

Figure 1-1: *Structure of an Atom*

The valence shell is the outermost the outermost energy shell. This part of the atom is of great concern in electronics and determines the type of conductance. The valence shell always "wants" to have eight valence electrons. If an atom has fewer than four valence electrons, it wants to lose them and it is considered a conductor. If there are more than four valence electrons, it wants to gain and is considered to be an insulator. If the atom has exactly four electrons, it shares the properties of both and is considered to be a semiconductor.

A balanced atom is when the total number of protons and electrons are equal. Other than valence effects, there are no electrical properties.

An ion is a atom that has lost or gained an electrons). This imbalance between the number of protons and electrons gives the atom a charge. When an atom loses electrons, it becomes a positive ion. When an atom has an excess of electrons, it is a negative ion. The amount of energy required to free a valance electron and create an ion varies from element to element.

Unlike charges have a mutual attraction and like charges repel each other. Whenever there is a difference in charge, that which is "more negative" will be attracted to that which is "more positive."

Current Flow

The movement (flow) of electrons through a conductor is called electricity or electron current. If a coulomb (6.25 x 1018 electrons) flows past a given point within one second, the current equals 1 ampere (A).

There are two theories for explaining current flow. The first is called "electron flow" and states the current moves from the negative (-) to the positive (+) of any power source. Most of the electronics industry adhere to this theory. Physicists and engineers use the "conventional current" theory which states that current flows from positive to negative.

The actual direction of current flow is not important when troubleshooting most electrical systems. Usually, it is more important to know if current is flowing or not. Remember to be consistent in your approach to current flow. Refer to Figure 1-2.

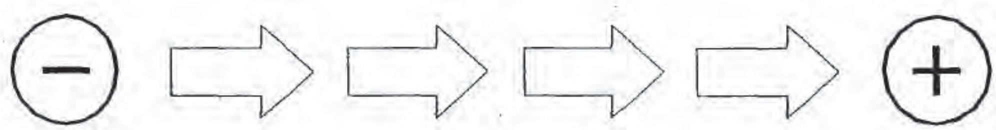

Figure 1-2: *Current Flow. "Electron Flow" Theory*

Conductor Types

Conductors

An electric current will flow easily through a conductor. Conductors are made of materials that are ready sources of free electrons (not attached to an atom).

Atoms or materials with fewer than half their valence electrons are considered conductors. Gold and silver are the best conductors because their valence orbits are nearly empty (one electron). The most common materials for conductors are:

1. Silver-not used heavily in electronics because of expense and the fact that it will oxidize
2. Copper-most commonly used
3. Gold-sometimes used for connectors. It does not oxidize and is very expensive
4. Aluminum-has variety of uses, but it gets brittle with age and use

Insulators

Insulators are materials that are not sources of free electrons. Atoms and materials that have more than half their valence electrons are considered insulators. Neon and helium are the best insulators because their valence orbits are full. The most common materials for insulators are:

1. Air
2. Plastic
3. Glass/fiberglass
4. Rubber
5. Ceramic/porcelain
6. Paper

Semi-Conductors

A semi-conductor has atoms and materials with half (sometimes nearly) of their valence electrons. Depending on temperature, biasing and use, a semi-conductor can either like a conductor or an insulator.

The most common materials for semi-conductors are: Germanium and silicon - both have four electrons in their valence orbits. Silicon is used approximately 99% of the time. Germanium about 1%. Another semi-conductor material Selenium has specialty uses and is light sensitive.

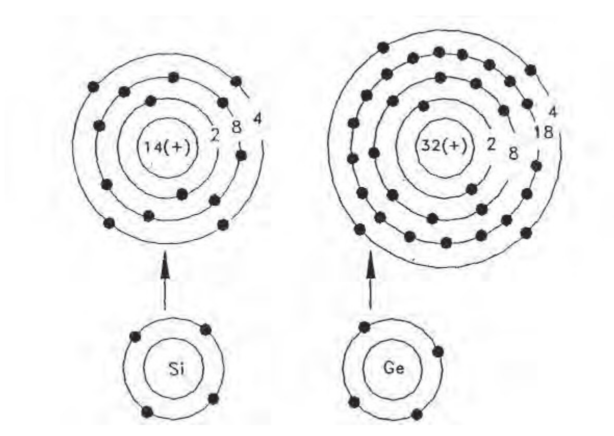

Figure 1-3: *Silicon And Germanium Atoms*

In general:

1. Atoms with four valence electrons are semi-conductors
2. Atoms with fewer than four valence electrons are conductors
3. Atoms with more than four valence electrons are insulators

Units of Electricity

Current

Current (I) is the flow (uncontrolled or controlled) of electrons through a conductor. Current flow results when a closed conductive path connects two different charges (or a potential difference).

Electron flow is capable of doing work, such as:

1. turning motors
2. lighting lamps
3. warming heaters, etc

The unit used for current measurement is the ampere (amp) and is symbolized by the letter: A. Microamps: μA. Milliamps: mA. An ampere is the flow of one coulomb per second. The formula for current calculation is: $I = E / R$.

Voltage

Electromotive Force (EMF) causes electrons to flow through a conductor. EMF provides the "pressure" that forces current through a circuit from negative to positive (electron flow theory). How strongly the current flows depends on the difference in charge between the most negative point and the most positive point.

The volt is the practical unit of measurement of EMF or potential differences. The word voltage (E), which is measured in volts (V), is substituted for EMF. Microvolts: μV. Millivolts: milliV. One volt is the EMF required to cause current to flow at the rate of one ampere through the resistance of one ohm. When there is a potential difference or a difference of electrical pressure, between two points, it simply means that a field of force exists that tends to move electrons from one point to another. Voltage is "across" or "dropped across" a component. The formula for voltage calculation is: $E = I*R$.

Resistance

Resistance (R) is the controlled opposition to the flow of current. This is a necessary element of every circuit. The property of a conductor which tends to hold, or restrict the flow of an electric current (opposes current flow). This is encountered in every circuit. Resistance can be, also, defined as electrical friction.

The unit of measurement is the ohm is symbolized by the Greek letter omega: Ω. The formula for resistance calculation is: $R = E / I$.

Power

Power (P) is defined as the amount of work accomplished or the amount of energy (typically heat) that is produced. Also, power is concerned with how fast the work is done. The power needed to do a specified amount of work depends on how much time it takes to do the work.

The unit of measurement is the watt and is symbolized by the capital letter: W. One watt of power is consumed when 1V pushes 1A through a circuit.

When calculating power, voltage and current must taken into consideration. The formulas for calculating power are: $P = E * I$ and $P = I^2 * R$.

Types of Current

Direct Current

Direct Current (DC) flows in only one direction. DC voltage has a steady polarity that does not reverse. DC voltages can be positive or negative.

Figure 1-4: *Positive DC Voltage*

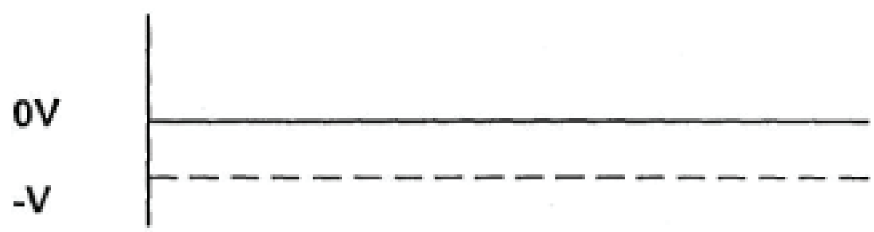

Figure 1-5: *Negative DC Voltage*

Alternating Current

Alternating Current (AC) reverses direction at a regular rate. The alternating voltage reverses in polarity. The polarity of the voltage source determines the direction of current flow. The rate of reversal is the frequency.

The magnitude of voltage is constantly changing (current conforms to voltage). Polarity is constantly reversing itself in order to get total current to change direction.

Compared to DC, the magnitude of the voltage or the current can be changed. The polarity of the voltage and direction of the current can not change.

Typically, AC power sources operate at a fairly low frequency. For low-wattage applications, it is easier to make DC devices than AC devices, such as batteries. In heavy-wattage installations, AC is much more practical to generate. It is also easier to transmit AC over long distance. Ease of transmission is why the power companies operate on AC.

An AC waveform is measured amplitude (voltage) and time (frequency).

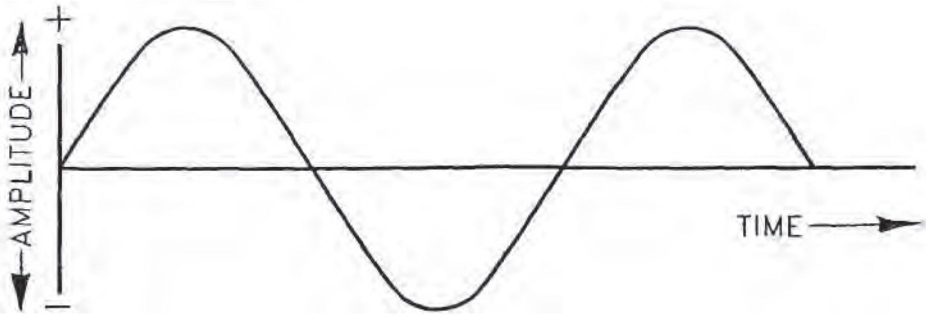

Figure 1-6: *AC Sine Waveform*

AC Measurement

Peak voltage (V_P) is value of each of the negative and positive half-cycle of an AC waveform that are equal.

Peak-to-Peak (V_{P-P}) voltage is the full amplitude cycle of the AC waveform (from positive peak to negative peak). The relationship is $V_{P-P} = 2\ V_P$.

Average voltage ($V_A v$) is the mathematically proven portion of the half cycle (V_P) that is equal to $0.637V_P$. Root-Mean-Square (RMS) or effective value is the most common way of specifying the amount of AC. This is the value that produces the same heat in a resistive circuit as DC of the same value. The formula is RMS = 0.707 V_P. Refer to Figure 1-7.

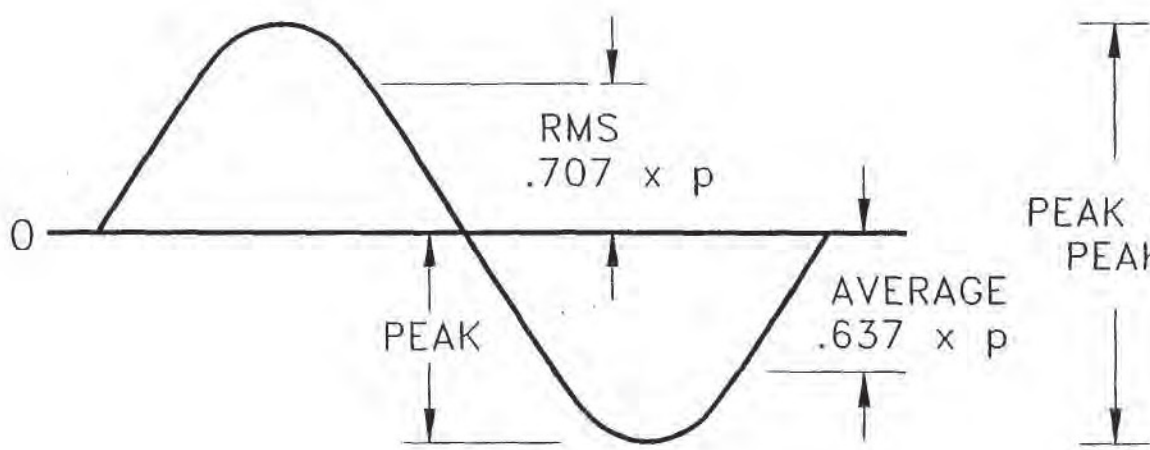

Figure 1-7: *AC Measurements*

AC waveforms can use negative or positive voltage levels for "zero" reference. That is the dividing line where the waveform goes more positive and then goes more negative. Refer to Figure 1-8.

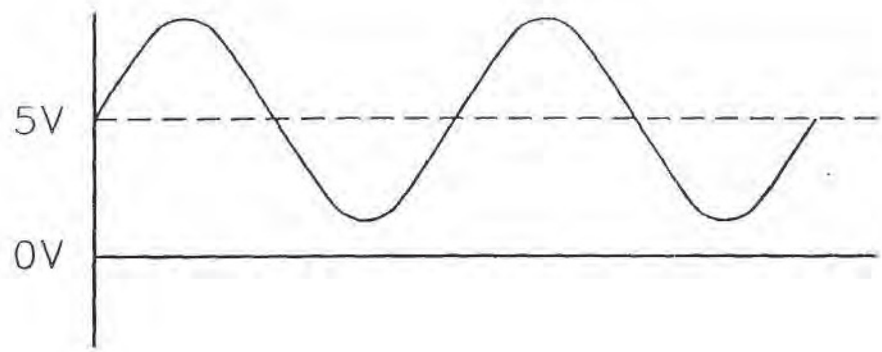

Figure 1-8: *AC Reference Level; Other Than Zero*

Other AC Waveforms

A saw-tooth waveform is when the amplitude values have a slow linear rise or fall and a sharp change back to the starting value.

A square waveform is an almost instantaneous rise and decay of voltage or current in a periodic pattern with time and with a constant peak value.

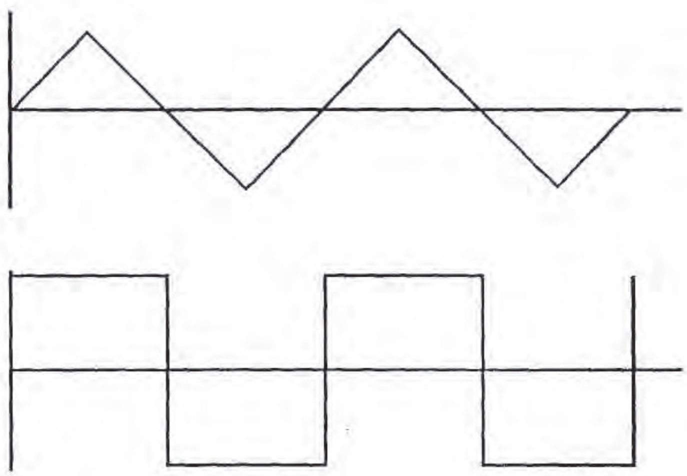

Figure 1-9: *Other AC Waveforms: Sawtooth and Square wave*

AC Advantages

The advantages of AC are:

1. cheaper to produce and use
2. AC can travel down a conductor much further than DC can
3. total power output is lower
4. thinner wire, less insulation, fewer utility poles

AC Waveform Terminology

The sine wave is a graph of a single cycle. It is based on a circle divided into 360 degrees and four quadrants.

A cycle is a single “back and forth” journey/travel by an electron.

A time period is the length of time it takes to complete a single cycle. Also referred to as: time (T). The time for a cycle is measured in fractions of a second.

Frequency is the rating of cycling and the number of cycles completed per second. The unit of measurement is the Hertz (Hz). Frequency and time have an inversely proportional relationship: $F = 1/T$ and $T = 1/F$.

All AC signals have both voltage and frequency; and therefore time.

Static Electricity

The definition of static is stationary or at rest. Static Electricity is electric charges that are at rest.

A material with atoms containing equal numbers of electrons and protons is electrically neutral. If the number of electrons in that material should increase or decrease, the material is left with a static charge. This can be caused by the friction between two dissimilar substances or by contact between a neutral body and a charged body.

Electrostatic Force

Electrostatic force is created between two charged bodies. Depending on the charge, it can be either an attractive or a repulsive force. The strength of force is affected by the amount of static charge contained within a body and the distance between the charged bodies.

Methods of Producing Voltage

Static Electricity is produced by rubbing two dissimilar materials together. It is not actually a useful form of power.

Piezoelectricity creates electricity by applying pressure to certain types of crystals.

The Photoelectric Effect produces a voltage when light is emitted onto certain substances.

The Thermoelectric Effect can produce electricity by subjecting two dissimilar metals to above normal temperatures.

A Chemical Action can produce electricity when two or more correct chemicals come together, their structures are altered and voltage is produced.

Electromagnetic Induction produces voltage by moving a conductor through a magnetic field.

Electromagnetic Induction

Induction is the transfer of electric energy from one circuit to another without the aid of electrical connections. This process is universally employed to generate electricity. Induction, also, makes possible the operation of electric transformers and the transmission of radio signals.

If a conductor is placed within a magnetic field, it develops a charge. If there is a closed conductive path, current will be induced to flow down the path.

When a coil is charged, a magnetic field is created around it. Part of the field overlaps the closed loop. When the coil's charge is changed, the magnetic field around it collapses, and part of it collapses onto the closed loop. The magnetic field collapses onto the closed loop induces current through the loop, and with AC you get a constant reverse of polarity.

The requirements of mutual inductance are:

1. presence of a magnetic field
2. closed conductive path
3. relative motion between them

The two general classifications of electromagnetic induction are Generator Action and Transformer Action.

Theory of Magnetism

The Magnet is an object that attracts such magnetic substances as iron or steel. It produces a magnetic field external to itself that reacts.

Magnetic Poles are the opposite ends of a magnet. One pole will tend to point towards the Earth's north pole if the magnet is freely suspended. This north-seeking pole is called the North Pole (+) of the magnet. The other pole is referred to as the South Pole (-).

A Magnetic Field consists of invisible lines of force that leave the north pole of a magnet and enter the south pole. The like poles (positive to positive) will repel each other and the unlike poles (positive to negative) will attract each other.

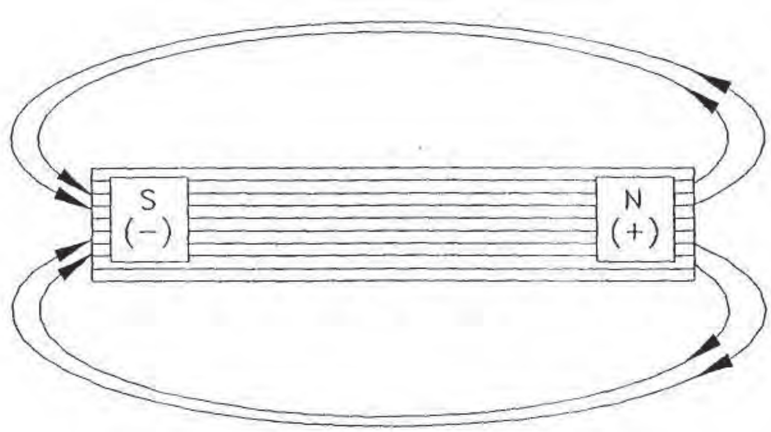

Figure 1-10: *Magnetic Line of Force*

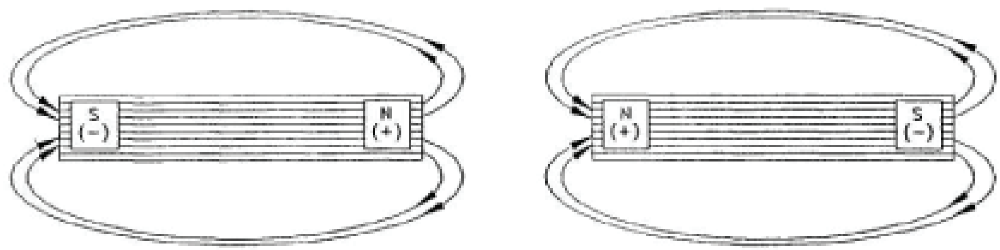

Figure 1-11: *Magnetic Pole Opposition*

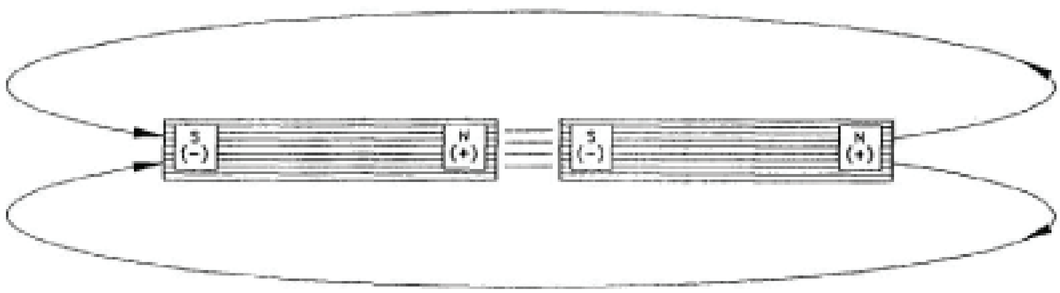

Figure 1-12: *Magnetic Pole Attraction*

Natural Magnets are found in nature. They are also called a lodestone or leading stone. Their composition is of an oxide of iron called magnetite.

Magnetic Variation is the difference between geographic and magnetic poles. This principle is very important when navigating using a magnetic compass.

Residual Magnetism is the slight amount of magnetism magnetic substance retains after being magnetized.

Permeability is the ability of a material to become magnetized.

The magnetic equivalent of resistance is reluctance (*R*). The similarities between magnetism and electricity are so strong that Ohm's law applies to magnetism also. In magnetic circuits, flux equals magneto motive force divided by reluctance.

Non-magnetized material has a random arrangement of magnetic charges within its atoms. In magnetized material, the charges of the atoms align themselves with the magnetic field. Any material that can be magnetized will be attracted to a magnetic field. When a non-magnetic material is placed within a magnetic field, there is no change to the field or object. When a magnetized material is placed within a magnetic field the field will change shape: it is easier to go through objects than air. The object then becomes magnetized.

When a circuit is turned on the conductor becomes magnetized (the magnetic field created around all conductive elements of circuit). The magnetic field is perpendicular (right angle) to the current path. All the electrical energy goes into the creation of magnetic field. For a brief period of time there is no current, as field begins to grow. As the field grows, less electrical energy is required for magnetic conversion, so current starts to flow (time is in nano-seconds).

When any circuit is turned off, the magnetic field collapses back on itself. It reconverts itself back into current, flowing in its original direction. Current will continue to flow until the magnetic field is completely collapsed.

Left-Hand Rule Of Thumb

When a coil is grasped in the left hand with the fingers pointing in the direction of current flow, that is, from negative to positive, the thumb will point toward the north pole of the coil. Whenever current flows through a conductor, a magnetic field is formed perpendicular to the flow of current. The strength of an electromagnet is directly proportional to the current carried by the wire coil and to the number of turns in that coil.

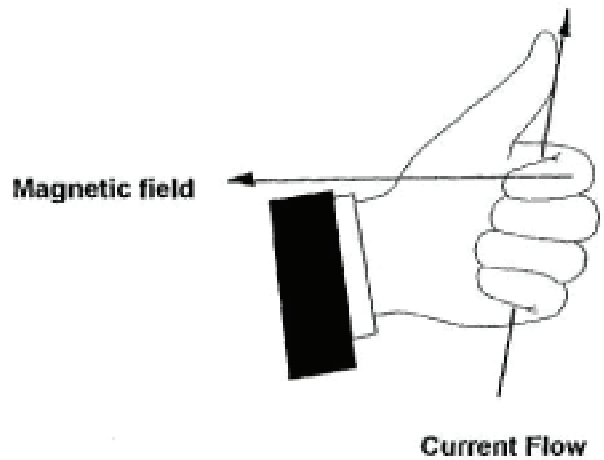

Figure 1-13: *Left-Hand Rule of Thumb*

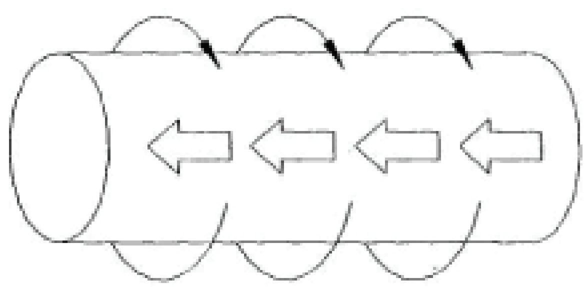

Figure 1-14: *Current Flow and Magnetic Field Directions*

Magnetic Devices

A Coil is one or more turns of a conductor designed for use in a circuit to produce inductance or an electromagnetic field. The lines of force produced by one turn of the coil combine with lines of force from other turns and thread through the coil, thus giving the coil a magnetic polarity. The Left-Hand Rule For Coils is used for determining the direction of the magnetic field.

Electromagnets are produced by using electric current to produce a magnetic field. A magnetic field exists around every conductor carrying current. If the current is very strong or the conductor is formed into a coil, the magnetic field strength increases.

A Solenoid is an electromagnet with a movable core. This movable core can be used to perform many mechanical functions and can operate electrical contacts, circuit breakers, and valves, etc. When the voltage is placed across the coil, the fixed core becomes an electromagnet. The movable core is attracted to the fixed core. When the charge is removed, the core becomes demagnetized and the spring pushes the plunger back out. The chief advantage is that they can be placed anywhere and controlled remotely by small switches or electronic control units.

Relays contain a fixed core and pivoting mechanical linkage. A magnetic field is used to open or close contacts on a switch. They are used for low-current switching applications. Consists of two parts: a coil and a magnetic switch. Refer to Figures 1-15 & 1-16.

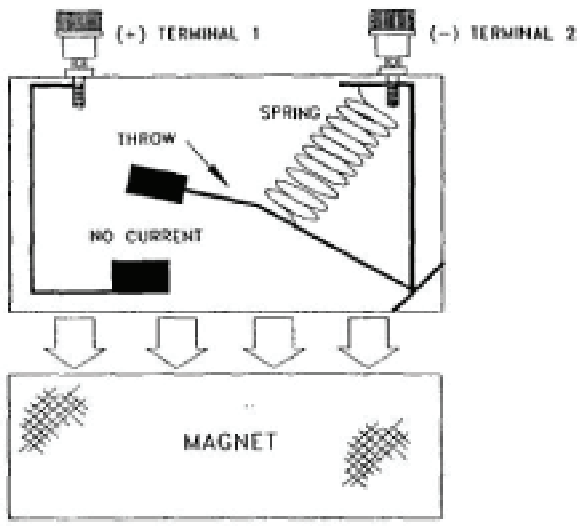

Figure 1-15: *Basic Relay Operation. No Magnetic Attraction with No Terminal Contact*

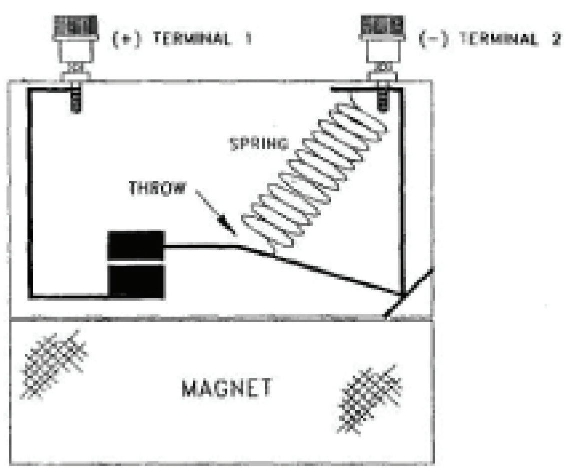

Figure 1-16: *Basic Relay Operation. Magnetic Attraction with Terminal Contact*

A magnetic recording head produces a varying magnetic field that can be stored on tape and played back from the tape. Refer to Figure 1-17.

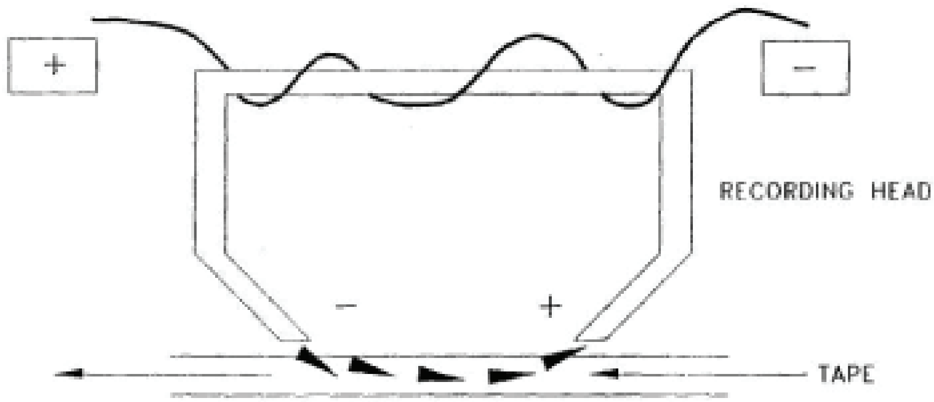

Figure 1-17: *Magnetic Recording Head*

Speakers have a movable coil is attached to a flexible cone that is placed around a fixed magnet. As the coil's charge is changed, its magnetic relationship to the core magnet changes. The movement of the coil causes the cone to vibrate.

Circuit Protection Devices

A short circuit is the most common cause of circuit failure. Circuit protection devices are utilized to prevent damage to the circuit. There are various types of circuit protection devices.

A Fuse is a thin strip of metal having a very low melting point. When current flowing through a fuse exceeds the capacity of the fuse, the metal strip melts and breaks the circuit. They have to be physically replaced after they "blow".

A Current Limiter is essentially a slow-blow fuse.

A Circuit Breaker is a manually operated switch that has an automatic tripping device. It serves a purpose similar to that a fuse. The major advantage of a circuit breaker is that they can be reset instead of replaced.

Thermal circuit breakers are tripped by excessive heat acting on a bimetallic strip. They cannot be reset till the temperature returns to normal.

Printed Circuit Boards

Printed Circuit Boards (PCBs) provide a mounting surface and the electrical current paths for the individual components of a system. Its surface is covered with copper foil and holes are drilled through the materials where component connections are made. PCBs allow for installation of hundreds of individual components into electronic equipment. Working with PCBs is very difficult and often special equipment and soldering/ desoldering techniques are needed.

Cathode Ray Tube

A Cathode Ray Tube (CRT) is basically, an oscilloscope or TV picture tube. They are designed to produce a picture on a screen. The picture is developed from a series of pulses and varying voltages applied to the elements of the tube.

CRT components are:

1. An electron gun which produces the electron beam.
2. The phosphorescent tube is where the beam is aimed and presented.
3. Deflecting devices control the movement of the electron beam.

Wavelength and Frequency

The length of a radio wave depends on its frequency (f). Frequency is the number of complete cycles of a periodic process per second. Frequency is measured in Hertz (Hz).

Wavelength is the distance from the crest of one wave to the next. Frequency is represented by the Greek letter lambda: λ.

The equation for wavelength is: λ = (300,000,000 m/s) / frequency (f)

The equation for frequency is: f = (300,000,000 m/s) / λ

Safety

Electrical Shock

High voltages are not necessary to cause fatal electrical shocks. Voltages as low as 15 volts have proven fatal. The amount of electrical current determines the severity of shock.

If any electrical shock has occurred, shut off the power and safely remove the victim from the electrical source. Call for medical assistance. Apply CPR until trained personnel can take over.

Equipment Damage

In addition to personnel safety, prevention of electrical damage to tools and equipment must practiced. Tools can cause an electrical shock, this can damage the tool, the equipment, the operator, or cause a fire hazard. Jewelry, such as watches and rings should not be worn when working on electrical equipment.

Safety precautions must be practiced around electrical equipment, no matter what the voltage or how safe it appears.