SUBCOURSE
OD1647

EDITION
8

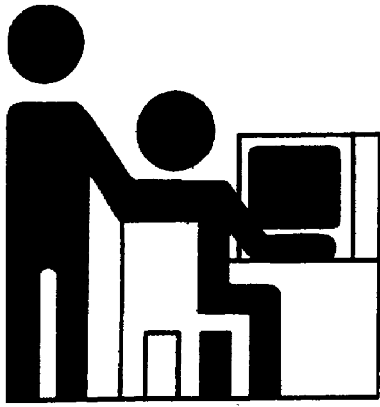
ELECTRONIC PRINCIPLES

AIPD

READINESS/
PROFESSIONALISM
THRU
GROWTH

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM



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ELECTRONIC PRINCIPLES

SUBCOURSE OD1647
EDITION 8

United States Army Combined Arms Support Command
Fort Lee, VA 23801-1809

7 Credit Hours
NEW: 1988

GENERAL

This subcourse is designed to introduce the student to the basic principles of electronics. By mastering this subcourse, the student should be able to adequately answer the practical exercise and examination questions that accompany the subcourse.

Additionally, the student should, upon completion of this subcourse, be able to put into practice the theories learned. Prior to beginning this subcourse, the student should have successfully completed subcourse 0D1633. Subcourse 0D1633 dealt with the elements of electricity, safety precautions, voltage, current, resistance, resistors, and the different types of electrical circuits encountered. The material presented in 00D1633 forms the basis of several of the theories presented in this subcourse. Therefore, it is recommended that the student master subcourse 0D1633 before proceeding with subcourse 0D1647.

Seven credit hours are awarded for successful completion of this subcourse

Lesson 1: ELECTRONIC PRINCIPLES

TASK 1: Describe magnetism, analyze inductive and capacitive circuits, and describe how alternating current is produced.

TASK 2: Describe basic fundamentals of semiconductors, including PNP and NPN transistors.

TASK 3: Describe the AN/USM-281C oscilloscope; including setup, operation, and use.

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LESSON 1

ELECTRONIC PRINCIPLES

TASK 1. Describe magnetism, analyze ,inductive and capacitive circuits, and how alternating current is produced.

CONDITIONS

Within a self-study environment: and given the subcourse text, without assistance.

STANDARDS

Within four hours

REFERENCES

No supplementary references are needed for this task.

1. Introduction

An Armament Repair Technician is required to know a great deal about the workings of most of the fire control equipment. In the Army's inventory. Since most of this equipment operates on some form of electrical energy, he should possess a knowledge of how this electricity is produced, as well as of the characteristics and effects caused by electricity.

Prior to proceeding with this subcourse, the student should have completed subcourse OD1633, which dealt with the elements of electricity, safety requirements used when working with electricity, voltage, current, resistance functions, Ohm's law and color codes of resistors. It additionally identified and analyzed series, parallel, and series-parallel circuits. The information presented in OD1633 is important to the successful completion of this subcourse. Therefore, it is recommended that the student master 0D1633 before proceeding with OD1647.

2. Magnetism

In order to properly understand the principles of electricity, it is necessary to study magnetism and the effects of magnetism on electrical equipment. Magnetism and electricity are so closely r: elated that the study of either subject would be incomplete without at least a basic knowledge of the other.

Much of today's modern electrical and electronic equipment could not function without magnetism. Modern computers, tape recorders, and video reproduction equipment use magnetized tape. High-fidelity speakers use magnets to convert amplifier outputs into audible sound. Electrical motors use magnets to convert electrical energy into mechanical energy; generators use magnets to convert mechanical energy into electrical energy.

a. *Magnetic Materials*. Magnetism is generally defined as that property of a material which enables it to attract pieces of iron. A material possessing this property is known as a magnet. The word originated with the ancient Greeks, who found stones possessing this characteristic. Materials that are attracted by a magnet, such as iron, steel, nickel, and cobalt, have the ability to become magnetized. These are called magnetic materials. Materials, such as paper, wood, glass, or tin, which are not attracted by magnets, are considered nonmagnetic. Nonmagnetic materials are not able to become magnetized.

(1) *Ferromagnetic Materials*. The most important group of materials connected with electricity and electronics are the ferromagnetic materials. Ferromagnetic materials are those which are relatively easy to magnetize, such as iron, steel, cobalt, and the alloys Alnico and Permalloy. An alloy is made by combining two or more elements, one of which must be metal. These new alloys can be very strongly magnetized; they are capable of obtaining a magnetic strength great enough to lift five hundred times their own weight.

(2) *Natural Magnets*. Magnetic stones, such as those found by the ancient Greeks, are considered to be natural magnets. These stokes had the ability to attract small pieces of iron in a manner similar to the magnets which are common today. However, the magnetic properties attributed to the

stones were products of nature and not the result of the efforts of man. The Greeks called these substances magnetite.

The Chinese are said to have been aware of some of the effects of magnetism as early as 2600 B.C. They observed that stones similar to magnetite, when freely suspended, had a tendency to assume a nearly north and south direction. Because of the directional quality of these stones, they were later referred to as lodestones or leading stones.

Natural magnets, which presently can be found in the United States, Norway, and Sweden, no longer have any practical use as it is now possible to easily produce more powerful magnets.

(3) *Artificial Magnets*. Magnets produced from magnetic materials are called artificial magnets. They can be made in a variety of shapes and sizes and are used extensively in electrical apparatus. Artificial magnets are generally made from special iron or steel alloys which are usually magnetized electrically. The material to be magnetized is inserted into a coil of insulated wire and a heavy flow of electrons is passed through the wire. Magnets can also he produced by stroking a magnetic material with magnetite, or with another artificial magnet. The forces causing magnetization are represented by magnetic lines of force, very similar in nature to the electrostatic lines of force.

Artificial magnets are usually classified as permanent or temporary, depending on their ability to retain their magnetic properties after the magnetizing forces have been removed. Magnets made from substances, such as hardened steel and certain alloys which retain a great deal of their magnetism, are called permanent magnets. These materials are relatively difficult to magnetize because of the opposition offered to the magnetic lines of force as the lines of force try to distribute themselves throughout the material. The opposition that a material offers to the magnetic lines of force is called reluctance. All permanent magnets are produced from materials having a high reluctance.

A material with a low reluctance, such as soft iron or annealed silicon steel, is relatively easy to magnetize but will retain only a small part of its

magnetism once the magnetizing force is removed. Materials of the type that easily lose most of their magnetic: strength are called temporary magnets. The amount of magnetism which remains in a temporary magnet is referred to as its residual magnetism. The ability of a material to retain an amount of residual magnetism is called the retentivity of the material.

The difference between a permanent and a temporary magnet has been indicated in terms of reluctance, a permanent magnet having a high reluctance and a temporary magnet having a low reluctance. Magnets are also described in terms of the permeability of their materials, or the ease with which magnetic lines of force distribute themselves throughout the material. A permanent. magnet, which is produced from a material with a high reluctance, has a low permeability. A temporary magnet, produced from a material with a low reluctance, would have a high permeability.

b. *Magnetic Polls.* The magnetic force surrounding a magnet is not uniform. There exists a great concentration of force at each end of the magnet and a very weak force at the center. Proof of this fact can be obtained by dipping a magnet into iron filings. It is found that many filings will cling to the ends of the magnet: while very few adhere to the center. The(two ends, which are the regions of the concentrated lines of force, are called the poles of the magnet. Magnets have two magnetic poles, and both poles have equal magnetic strength.

(1) *Law of Magnetic Poles.* If a bar magnet is suspended freely on a string, it will align itself in a north and south direction. When this experiment is repeated, it is found that the same pole of the magnet will always swing toward the north geographical pole of the earth. Therefore, it is called the north-seeking pole or simply the north pole. The other pole of the magnet is the south--seeking pole or the south pole.

A practical use of the directional characteristic of the magnet is the compass, a device in which a freely rotating magnetized needle indicator points toward the north pole. The realization that the poles of a suspended magnet always move to a definite position gives an indication that the opposite poles of a magnet have opposite magnetic polarity.

The law previously stated regarding the attraction and repulsion of charged bodies may also be applied to magnetism if the pole is considered as a charge. The north pole of a magnet will always be attracted to the south pole of another magnet and will show a repulsion to a north pole. The law for magnetic poles is: <u>Like poles repel, unlike poles attract</u>.

(2) *The Earth's Magnetic Poles*. The fact that a compass needle always aligns itself in a particular direction, regardless of its location on earth, indicates that the earth is a huge natural magnet. The distribution of the magnetic force about the earth is the same as that which might be produced by a giant bar magnet running through the center of the earth. The magnetic axis of the earth is located about 150 from its geographical axis thereby locating the magnetic poles some distance from the geographical poles. The ability of the "north pole" of the compass needle to point toward the north geographical pole is due to the presence of the magnetic pole nearby. The magnetic pole is named the "Magnetic North Pole". However, in actuality, it must have the polarity of a magnet's "south pole" since it attracts the north pole of a compass needle. The reason for this conflict in terminology can be traced to the early users of the compass. Knowing little about magnetic effects, they. called the end of the compass needle that pointed towards the north geographical pole, the "north pole" of a compass. With our present knowledge of magnetism, we know the "north pole" of a compass needle (a small bar magnet) can be attracted only by an unlike magnetic pole, that is a pole with the same magnetic polarity as the "south pole" of a magnet. In reality, the "north pole" of a magnet is a north-seeking pole.

c. *Theories of Magnetism*.

(1) *Weber's Theory*. A popular theory of magnetism considers the molecular alignment of the materials. This is known as Weber's Theory. This theory assumes that all magnetic substances are composed of tiny molecular magnets. Any unmagnetized material has had the magnetic forces of its molecular magnets neutralized by adjacent molecular magnets, thereby eliminating any magnetic effect. A magnetized material will have most of its molecular magnets lined up so that the north pole of each molecule points in one direction and the south pole faces the opposite direction. A

material with its molecules thus aligned will have one effective north pole, and one effective south pole. An illustration of Weber's Theory is shown in figure 1 where a steel bar is magnetized by stroking. When a steel bar is stroked several times in the same direction by a magnet, the magnetic force from the north pole of the magnet causes the molecules to align themselves.

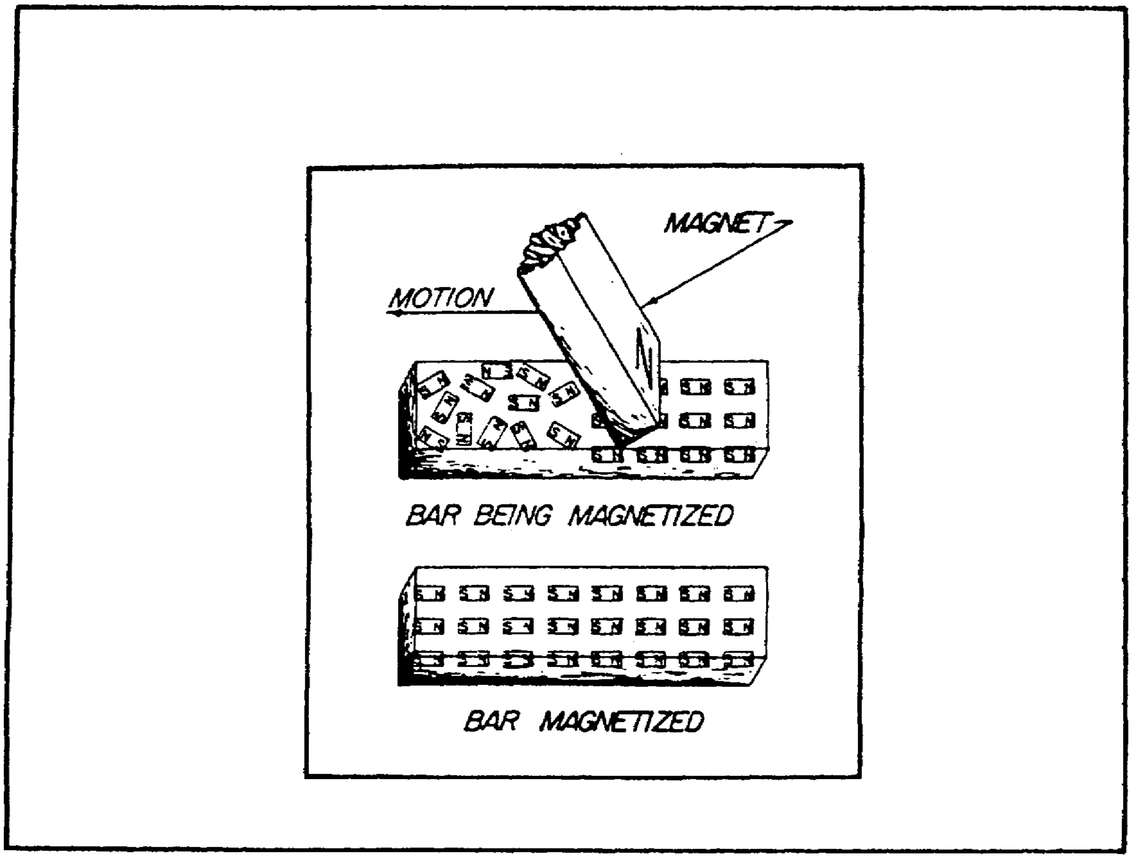


FIGURE 1. MOLECULAR MAGNETS (WEBER'S THEORY).

(2) *Domain Theory*. A more modern theory of magnetism is based on the electron spin principle. From the study of atomic structure, it is known that all matter is composed of vast quantities of atoms, each atom containing one or more orbital electrons. The electrons are considered to orbit in various shells and subshells, depending upon their distance from the nucleus. The structure of the atom has previously been compared to the solar system, wherein the electrons orbiting the nucleus correspond to the planets orbiting the sun. Along with its orbital motion about the sun, each planet also revolves on its axis. It. is believed that the

electron also revolves on its axis as it orbits the nucleus of an atom.

It has been experimentally proven that an electron has a magnetic field about it, together with an electric field. The effectiveness of the magnetic field of an atom is determined by the number of electrons spinning in each direction.. If an atom has equal numbers of electrons spinning in opposite directions, the magnetic fields surrounding the electrons cancel one another, and the atom is unmagnetized. However, if more electrons spin in one direction than another, the atom is magnetized. An atom with an atomic number of 26, such as iron, has 26 protons in the nucleus and 26 revolving electrons orbiting its nucleus. If 13 electrons are spinning in a clockwise direction and 13 electrons are spinning in a counterclockwise direction, the opposing magnetic fields will be ·neutralized. When more than 13 electrons spin in either direction, the atom is magnetized. An example of a magnetized atom of iron is shown in figure 2.

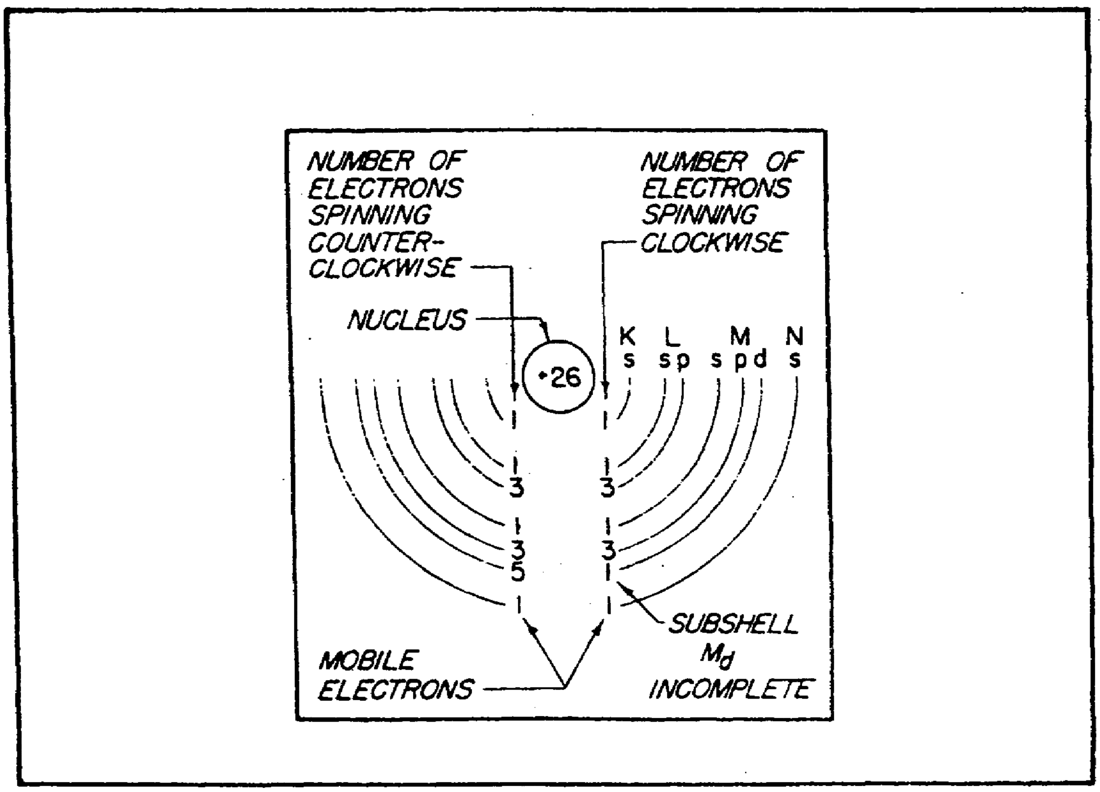


FIGURE 2. IRON ATOM (DOMAIN THEORY).

d. *Magnetic Fields*. The space surrounding a magnet where magnetic forces act is known as the magnetic field.

A pattern of this directional force can be obtained by performing an experiment with iron filings (figure 3). A piece of glass is placed over a bar magnet, and the iron filings are then sprinkled on the surface of the glass. The magnetizing force of the magnet will be felt through the glass, and each iron filing becomes a temporary magnet. If the glass is now tapped gently, the iron particles will align themselves with the magnetic(field surrounding the magnet, just as the compass needle did previously. The filings form a definite pattern, which is a visible representation of the forces comprising the magnetic field. Examination of the arrangements of iron filings in figure 3 will indicate that the magnetic field is very strong at the poles and weakens as the distance from the poles increases. It is also apparent that the magnetic field extends from one pole to the other, constituting a loop about the magnet.

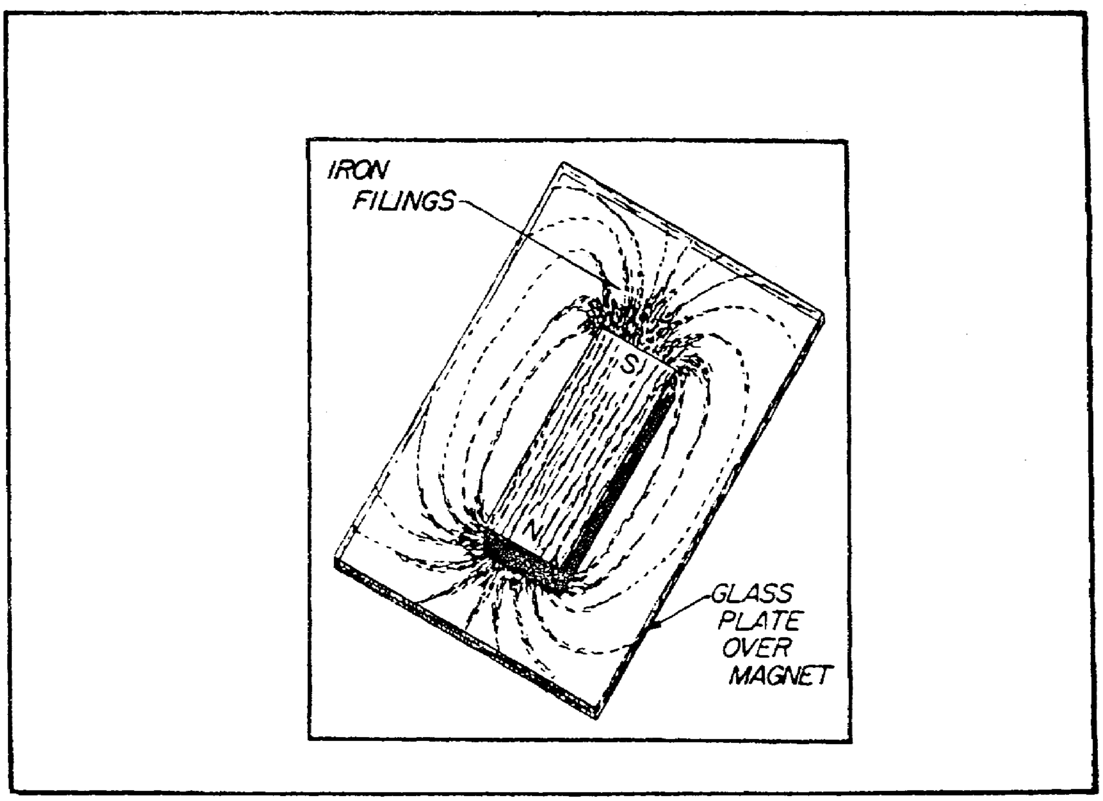


FIGURE 3. PATTERN FORMED BY IRON FILINGS.

(1) *Lines of Force*. To further describe and work with magnetic phenomena, lines are used to represent the force existing in the area surrounding a magnet. (figure 4). Theses lines, called MAGNETIC LINES OF FORCE, do not actually exist, but are imaginary lines used to illustrate and describe the pattern of the magnetic field. The magnetic lines of force are assumed to emanate from the north pole of a magnet, pass through the surrounding space, and enter the south pole. The lines of force then travel inside the magnet from the south pole to the north pole, thus completing a closed loop.

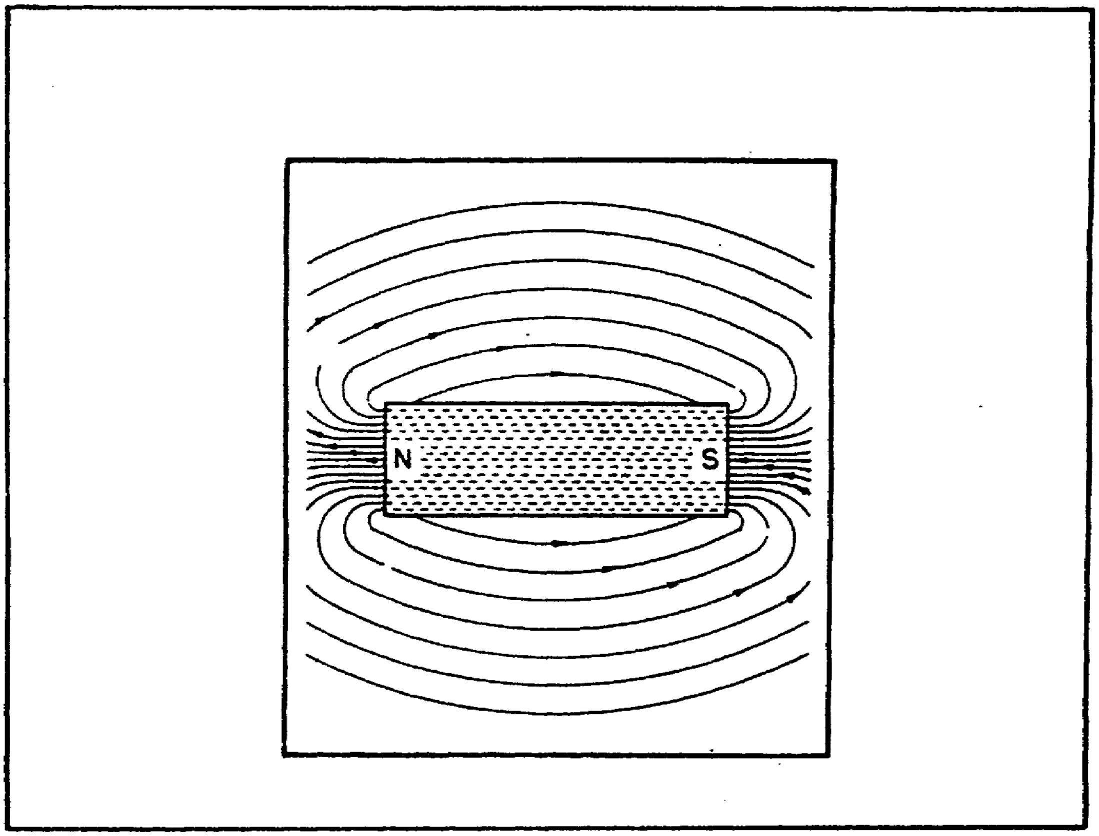


FIGURE 4. BAR MAGNET SHOWING LINES OF FORCE.

When two magnetic poles are brought close together, the mutual attraction or repulsion of the poles produces a more complicated pattern than that of a single magnet. These magnetic lines of force can be plotted by placing a compass at various points throughout the magnetic field, or they can be roughly illustrated by the use of iron filings as before. A diagram of magnetic poles placed close together is shown in figure 5.

(2) *Characteristics of Magnetic tines of Force*. Although magnetic lines of force are imaginary, a simplified version of many magnetic phenomena can be explained by assuming the magnetic lines to have certain real properties. The lines of force can be compared to rubber bands which stretch outward when a force is exerted upon them and contract when the force is removed. The characteristics of magnetic lines of force can be described as follows:

(a) Magnetic lines of force are continuous and will always form closed loops.

(b) Magnetic lines of force will. never cross one another.

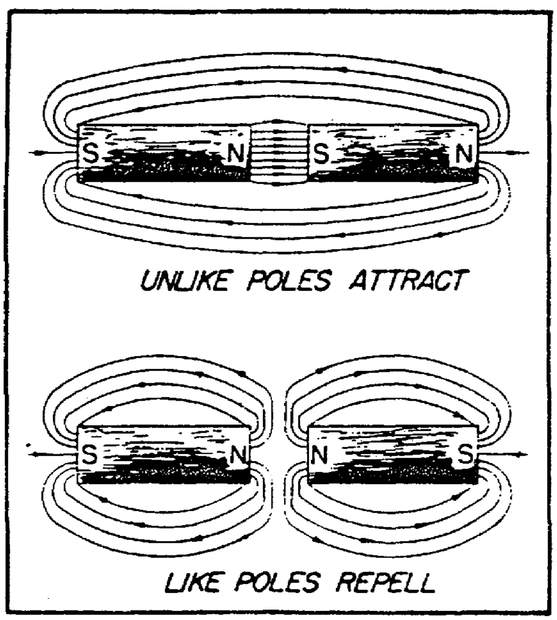


FIGURE 5. MAGNETIC POLES IN CLOSE PROXIMITY.

(c) Parallel magnetic lines of force traveling in the same direction repel one another. Parallel lines of magnetic force traveling in opposite directions tend to unite with each other and form into single lines traveling in a direction determined by the magnetic poles creating the lines of force.

(d) Magnetic lines of force tend to shorten themselves. Therefore, the magnetic lines of force existing between two unlike poles cause the poles to be pulled together.

(e) Magnetic lines of force pass through all materials, both magnetic and nonmagnetic.

(f) Magnetic lines of force always enter or leave a magnetic material at right angles to the surface.

e. *Magnetic Effects*.

(1) *Magnetic Flux*. The total number of magnetic lines of force leaving or entering the pole of a magnet is called MAGNETIC FLUX. The number of flux lines per unit area is known as the FLUX DENSITY.

(2) *Field Intensity*. The intensity of a magnetic field is directly related to the magnetic force exerted by the field.

(3) *Attraction/Repulsion*. The intensity of attraction or repulsion between magnetic poles may be described by a law almost identical to Coulomb's Law of Charged Bodies. The force between two poles is directly proportional to the product of the pole strengths and inversely proportional to the square of the distance between the poles.

(4) *Magnetic Induction*. Magnetism can be induced in a magnetic material by several means. The magnetic material may be placed in the magnetic field, brought into contact with a magnet, or stroked by a magnet. Stroking and contact both indicate the actual conduct of the material but are considered in magnetic studies as magnetizing by INDUCTION.

It has been previously stated that all substances that are attracted by a magnet are capable of becoming magnetized. The fact that a material is

attracted by a magnet indicates the material must itself be ;a magnet at the time of attraction.

With the knowledge of magnetic fields and magnetic lines of force developed up to this point, it is simple to understand the manner in which a material becomes magnetized when brought near a magnet. As an iron nail is brought close to a bar magnet (figure 6) some of the flux lines emanating from the north pole of the magnet pass through the iron nail in completing their magnetic path. Since magnetic lines of force travel inside a magnet from the south pole to the north pole, the nail will be magnetized in such a polarity that its south pole will be adjacent to the north pole of the bar magnet. There is now an attraction between the two magnets.

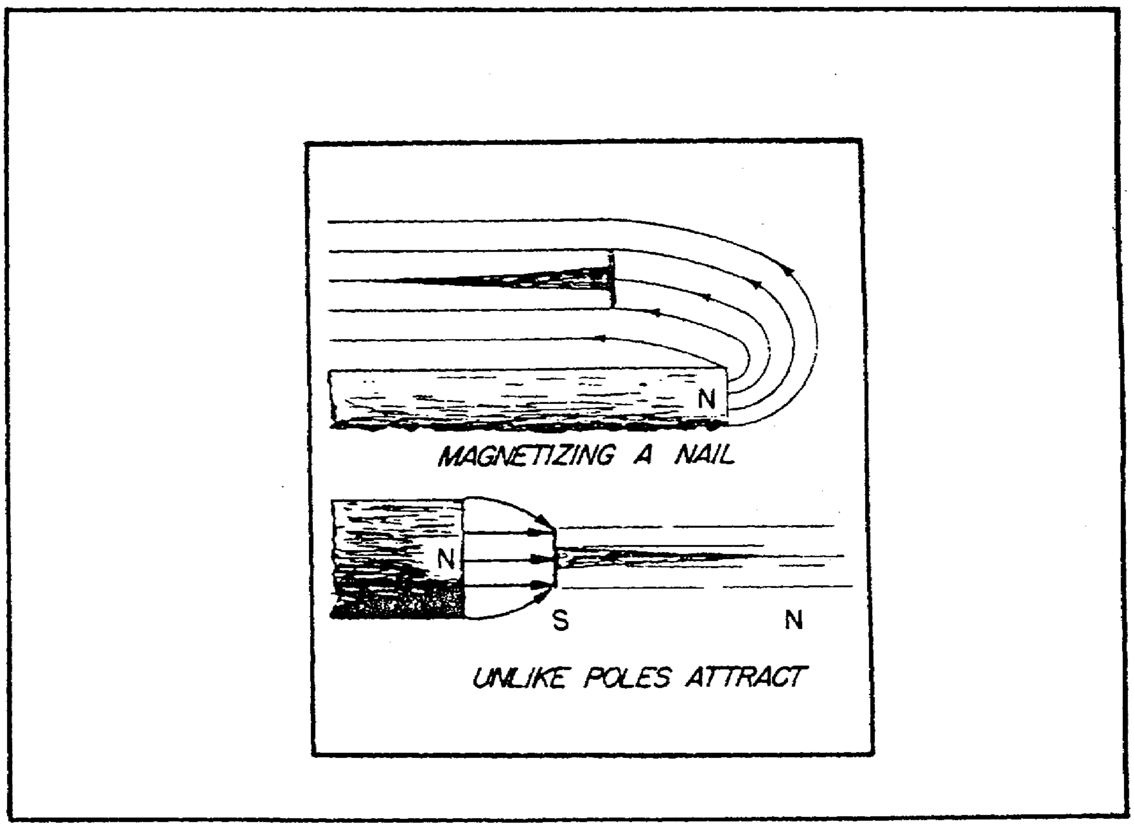


FIGURE 6. MAGNETIZED NAIL.

If another nail is brought. In contact with the end of the first nail, it will be magnetized by induction. This process can be repeated until the strength of the magnetic flux weakens as the distance from the bar magnet increases. However, as soon as the first iron nail is pulled away from the bar magnet, all the nails will fall. The reason for this is that each nail becomes a temporary magnet, and as soon as the magnetizing force is removed, their domains once again assume a random distribution.

Magnetic induction will always produce a pole polarity on the material being magnetized opposite that of the adjacent pole of the magnetizing force. It is sometimes possible to bring a weak north pole of a magnet near a strong magnetic north pole and note the attraction between the poles. The weak magnet, when placed within the magnetic field of the strong magnet, has its magnetic polarity reversed by the field of the stronger magnet. Therefore, it is attracted to the opposite pole. For this reason, it is important to keep a very weak magnet, such as a compass needle, away from a very strong magnet.

(5) *Magnetic Shielding*. There is no known INSULATOR for magnetic flux. If a nonmagnetic material is placed in a magnetic field, there is no appreciable change in the magnetic flux; that is, the flux penetrates the nonmagnetic material. For example, a glass plate placed between the poles of a horseshoe shaped magnet. will have no appreciable effect on the field, although glass itself is a good insulator in an electric circuit. If a magnetic material (for example, soft iron) is placed in a magnetic field, the flux may be redirected to take advantage of the greater permeability of the magnetic material, as shown in figure 7 on the following page. Permeability is the quality of a substance which determines the ease with which it can be magnetized.

The sensitive mechanisms of electric instruments and meters can be influenced by stray magnetic fields, which will cause errors in their readings. Because instrument mechanisms cannot be insulated from magnetic flux it is necessary to employ some means of directing the flux around the instrument. This is accomplished by placing a soft--iron case, called a MAGNETIC SCREEN or SHIELD, about the instrument. Because the flux is established more readily through the iron (even though the path is longer) than through the air inside the case, the instrument is effectively shielded, as shown in figure 8 on the following page.

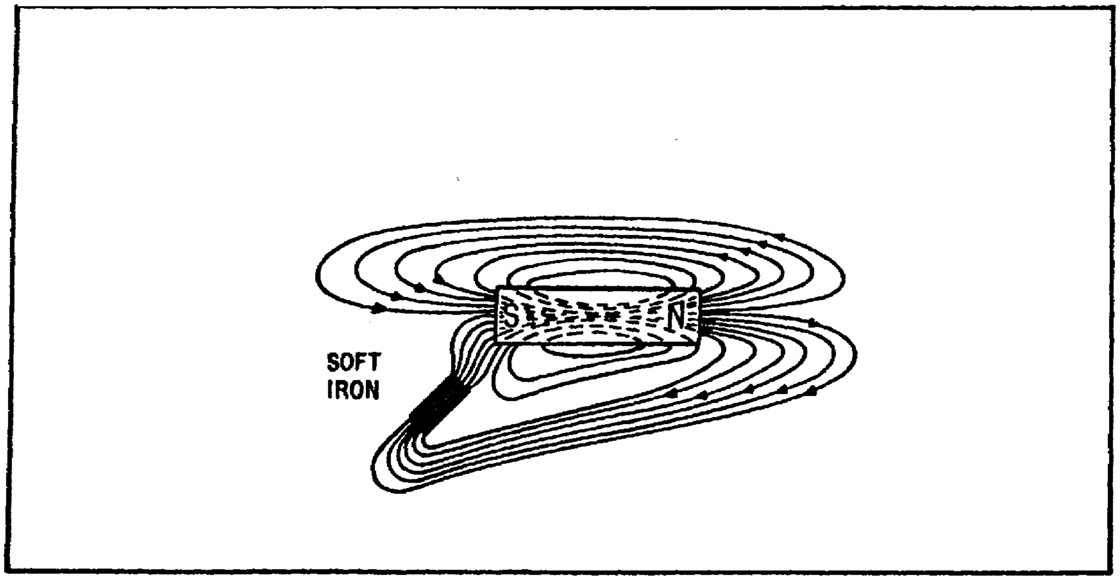


FIGURE 7. EFFECTS OF A MAGNETIC SUBSTANCE IN A MAGNETIC FIELD.

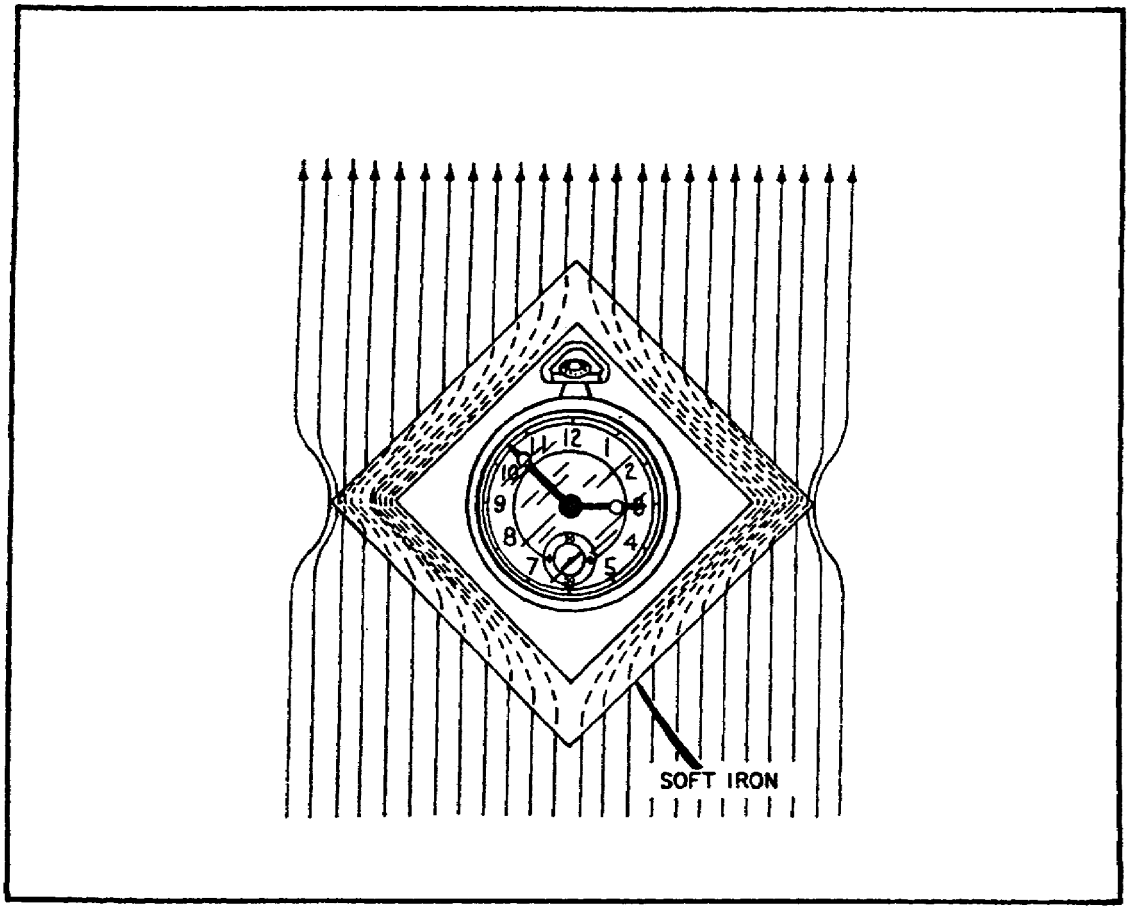


FIGURE 8. MAGNETIC SHIELD.

f. *Magnetic Shapes*. Because of the many uses of magnets, they are found in various shapes and sizes. However, magnets usually come under one of three general classifications: bar magnets, horseshoe magnets, or ring magnets.

(1) *Bar Magnets*. The bar magnet is most often used in schools and laboratories for studying the properties and effects of magnetism. In the preceding material, the bar magnet proved very helpful in demonstrating magnetic effects.

(2) *Horseshoe Magnets*. The shape of the magnet most frequently used in electrical and electronic equipment is called the horseshoe magnet. A horseshoe magnet is similar to a bar magnet but is bent in the shape of a horseshoe. The horseshoe magnet provides much more magnetic strength than a bar magnet of the same size and material because of the closeness of the magnetic poles. The magnetic strength from one pole to another is greatly increased due to the concentration of the magnetic field in a similar area. Electrical measuring devices quite frequently use horseshoe-type magnets.

(3) *Ring Magnets*. Another type of magnet is the ring magnet, which is used for computer memory cores. A common application for a temporary ring magnet would be the shielding of electrical instruments.

g. *Care of Magnets*. A piece of steel that has been magnetized can lose much of its magnetism by improper handling. If it is jarred or heated, there will be a disalignment of its domains, resulting in the loss of some of its effective magnetism. Had this piece of steel formed the horseshoe magnet of a meter, the meter would no longer be operable or would give inaccurate readings. Therefore, care must be exercised when handling instruments containing magnets. Severe jarring or subjecting the instrument to high temperatures will damage the device.

A magnet may also become weakened from loss of flux. Thus, when storing magnets, one should always try to avoid excess leakage of magnetic flux. A horseshoe magnet should always be stored with a keeper, a soft iron bar used to join the magnetic poles. By using the keeper when the magnet is stored, the magnetic flux will

continuously circulate through the magnet and not leak off into space.

When bar magnets are stored, the same principle must. he remembered. Therefore, bar magnets should always be stored in pairs with a north pole and a south pole placed together. This provides a complete path for the magnetic flux without flux leakage.

3. Inductance

The study of inductance presents a very challenging but rewarding segment of electricity. It is challenging, in the sense that new concepts are being introduced. The study of inductance is rewarding in the sense that a thorough understanding of it will. enable the student to acquire a working knowledge of electrical circuits more rapidly.

a. *Characteristics of Inductance*. Inductance is the characteristic of an electrical circuit that opposes the starting, stopping, or changing of current . The above statement is of such importance to the study of inductance that it bears repeating. <u>Inductance is the characteristic of an electrical conductor that OPPOSES A CHANGE IN CURRENT</u>. The symbol for inductance is L, and the basic unit of inductance is the HENRY (H). One Henry is equal to the inductance required to induce one volt in an inductor by a change of current of one ampere per second.

One does not have to look far to find a physical analogy of inductance. Anyone who has ever had to push a heavy load (wheelbarrow, car, etc.) is aware that it takes more work to start the load moving than it does to keep it, moving. Once the load is moving, it; is easier to keep the load moving than to stop it again. This is because the load possesses the property of INERTIA. Inertia is the characteristic of mass which opposes a CHANGE in velocity. Inductance has the same effect on current: in an electrical circuit as inertia has on the movement of a mechanical object. It requires more energy to start or stop the current than it does to keep it flowing.

b. *Electromotive Force (EMF).* Electromotive force is a difference of potential or voltage which exists between two points in an electrical circuit. In generators and inductors, the emf is developed by the action between the magnetic field and the electrons in a conductor (shown in figure 9).

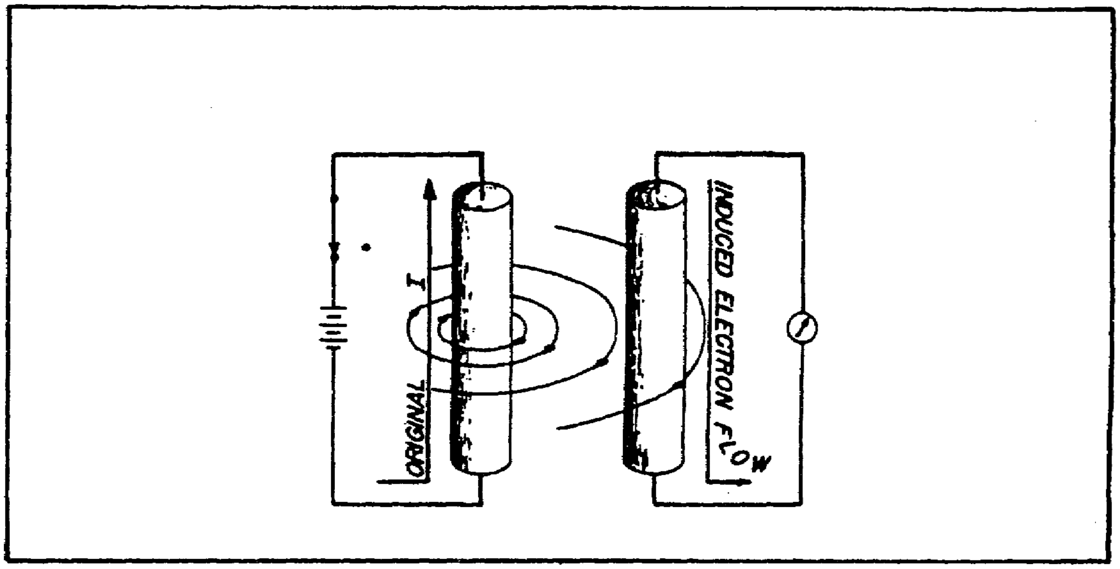


FIGURE 9. GENERATION OF AN EMF IN AN ELECTRICAL CONDUCTOR.

When a magnetic field moves through a stationary metallic conductor, electrons are dislodged from their orbits. The electrons move in a direction determined by the movement of the magnetic lines of flux. This is shown in figure 10 on the following page.

The electrons move from one area of the conductor into another area. The area that the electrons moved from has fewer negative charges (electrons) and becomes positively charged. The area the electrons move into becomes negatively charged. This is also shown in figure 10.

The difference between the charges in the conductor is equal to a difference of potential (or voltage). This voltage caused by the moving magnetic field is called the electromotive force (emf).

In simple terms, the action of a moving magnetic field on a conductor can be compared to the action of a broom. Consider the moving magnetic field to be a moving broom. As the magnetic broom moves

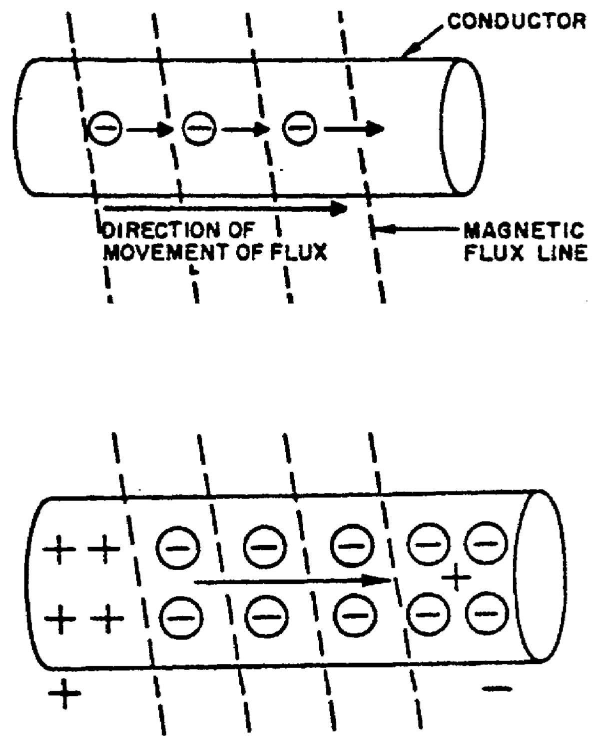


FIGURE 10. MOVEMENT OF FLUX AND ELECTRONS IN A CONDUCTOR.

along (through) the conductor, it gathers up and pushes electrons before it, as shown in figure 11 (on the following page).

The area from which electrons are moved becomes positively charged, while the area into which the electrons are moved becomes negatively charged. The potential difference between these two areas is the electromotive force or emf.

c. *Self-Inductance*. Even a perfectly straight length of conductor has some inductance. As you know, current in a conductor produces a magnetic field surrounding the conductor. When the current changes, the magnetic field changes. This causes relative motion between the magnetic field and the conductor, and an emf is induced in the conductor. The emf is called a SELF-INDUCED EMF because it is induced in the conductor carrying the current. This cmf is also referred to as COUNTER ELECTROMOTIVE FORCE (cemf). The polarity of the counter electromotive force is in the opposite direction to the applied voltage of the conductor. The overall effect will be to oppose a change in current magnitude. This effect is summarized by Lenz's law which states that: THE INDUCED EMF IN ANY CIRCUIT IS ALWAYS IN A DIRECTION TO OPPOSE THE EFFECT THAT PRODUCED IT.

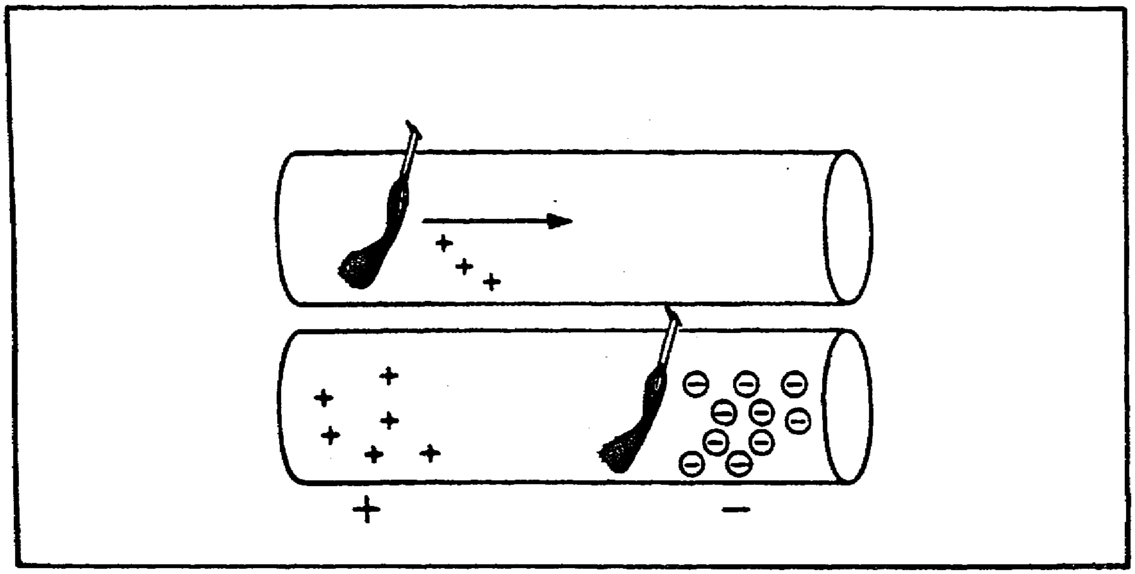


FIGURE 11. MOVEMENT OF A MAGNETIC FIELD THROUGH A CONDUCTOR.

If the shape of the conductor is changed to form a loop, then the electromagnetic field around each portion of the conductor cuts across some other portion of the same conductor. This is shown in its simplest form in figure 12 on the following page. A length of conductor is looped so that two portions of the conductor lie next to each other. These portions are labeled conductor 1 and conductor 2. When the switch is closed, current (electron flow) in the conductor produces a magnetic field around ALL portions of the conductor. For simplicity, the magnetic field (expanding lines of flux) is shown in a single plane that is perpendicular to both conductors. Although the expanding field of flux originates at the same time in both conductors, it is considered as originating in conductor 1, its effect on conductor 2 will be explained. With increasing current, the flux field expands outward from conductor 1, cutting across a portion of conductor 2. This results in an induced emf in conductor 2, as shown by the dashed arrows in figure 12.

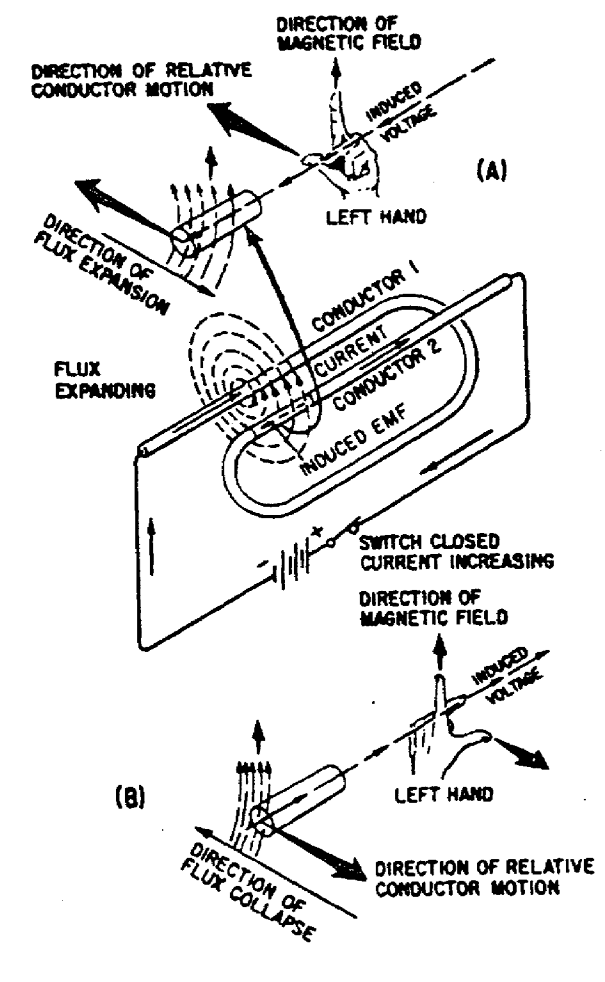


FIGURE 12. SELF-INDUCTANCE.

The direction of this induced voltage may be determined by applying the LEFT-HAND RULE FOR GENERATORS. This rule is applied to a portion of conductor 2 that is "lifted" and enlarged for this purpose in figure 12, view A, on the previous page. This rule states that if you point the thumb of your left hand in the direction of relative motion of the conductor and your index finger in the direction of the magnetic field, your middle finger, extended as shown, will now indicate the direction of the induced current, which will generate the induced voltage (cemf) as shown.

In figure 12, view B, the same section of conductor 2 is shown after the switch has been opened. The flux field is collapsing. Applying the left-hand rule in this case shows that the reversal of flux MOVEMENT has caused a reversal in the direction of the induced voltage. The induced voltage is now in the same direction as the battery voltage. The most important thing to note is that the self-induced voltage opposes BOTH changes in current. That is, when the switch is closed, this voltage delays the initial buildup of current by opposing the battery voltage. When the switch is opened, it keeps the current flowing in the same direction by aiding the battery voltage.

From the above explanation, it can be seen that when current is building up, it produces a growing magnetic field. This field induces an emf in the direction opposite to the actual flow of current. This induced emf opposes the growth of the current and the growth of the magnetic field. If the increasing current had not set up a magnetic field, there would have been no opposition to its growth. The whole reaction, or opposition, is caused by the creation or collapse of the magnetic field, the lines of which, as they expand or contract, cut across the conductor and develop the counter emf.

Since all circuits have conductors in them, we can assume that all circuits have inductance. However, inductance has its greatest effect only when there is a change in current. Inductance does NOT oppose current, only a CHANGE in current. Where current is constantly changing, as in an ac circuit, inductance has more effect.

(1) *Forming Inductors*. To increase the property of inductance, the conductor can be formed into a loop or coil. A coil is also called an inductor.

Figure 13 shows a conductor formed into a colt.

Current through one loop produces a magnetic field that encircles the loop in the direction as shown in figure 13, view A. As current increases, the magnetic field expands and cuts all the loops as shown in figure 13, view B. The current in each loop affects all other loops. The field cutting the other loop has the effect of increasing the opposition to a current change.

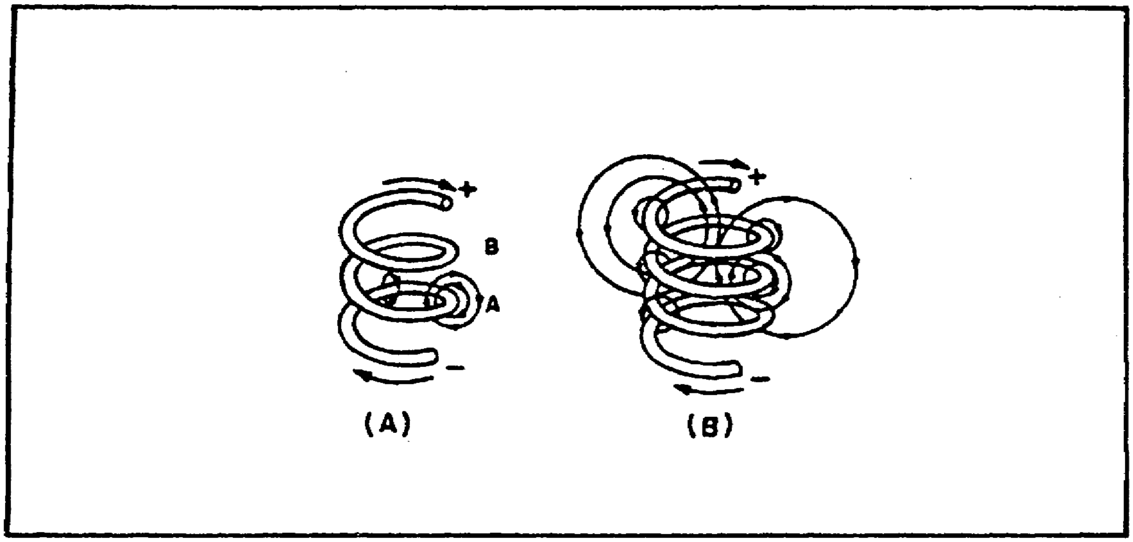


FIGURE 13. INDUCTANCE.

(2) *Classification of Inductors*. Inductors are classified according to the core type. The core is the center of the inductor just as the core of an apple is the center of an apple. The inductor is made by forming a coil of wire around a core. The core material is normally one of two basic types:

soft-iron or air. An iron-core inductor and its schematic symbol (which is represented with lines across the top of it to indicate the presence of an iron core) are shown in figure 14, view A, on the following page. The air-core inductor may be nothing more than a coil of wire, but it is usually a coil formed around a hollow form of some nonmagnetic material such as cardboard. This material serves no purpose other than to hold the shape of the coil. An air-core inductor and its schematic symbol are shown in figure 14, view B.

(3) *Factors Affecting Coil Inductance*. There are several physical factors which affect the inductance of a coil. They include the number of

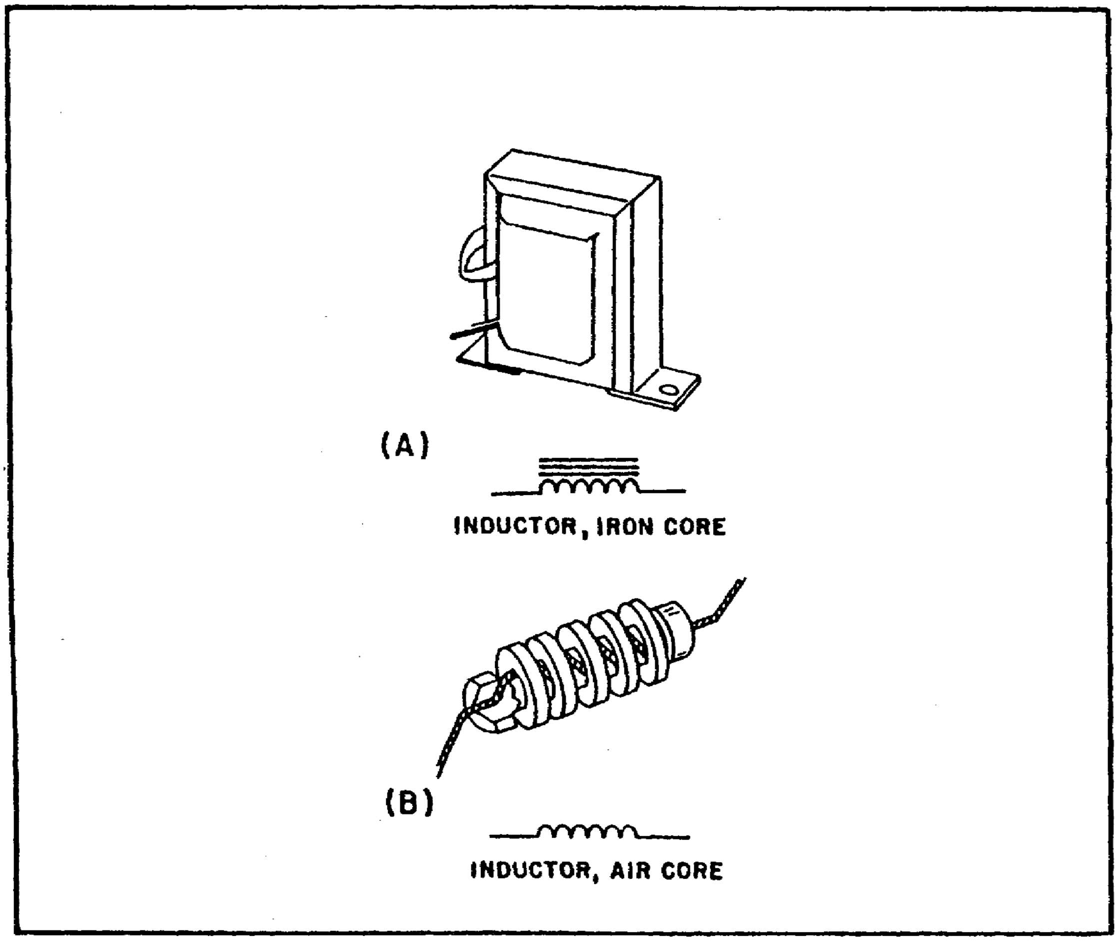


FIGURE 14. INDUCTOR TYPES AND SCHEMATIC SYMBOLS.

turns in the coil, the diameter of the coil, the coil length, the type of material used in the core, and the number of layers of windings in the coil.

(a) *Number of Turns in a Coil*. Inductance depends entirely upon the physical construction of the circuit, and can only be measured with special laboratory instruments. Of the factors mentioned, consider first how the number of turns affects the inductance of a coil. Figure 15 on the following page shows two coils. Coil (A) has two turns and coil (B) has four turns. In coil (A), the flux field set up by one loop cuts one other loop. In coil (B), the flux field set up by one loop cuts three other loops. Doubling the number of turns in the coil will produce a field twice as strong; cutting twice the number of turns will induce four times the voltage. Therefore, it can be said that the <u>inductance varies as the square of the number of turns</u>.

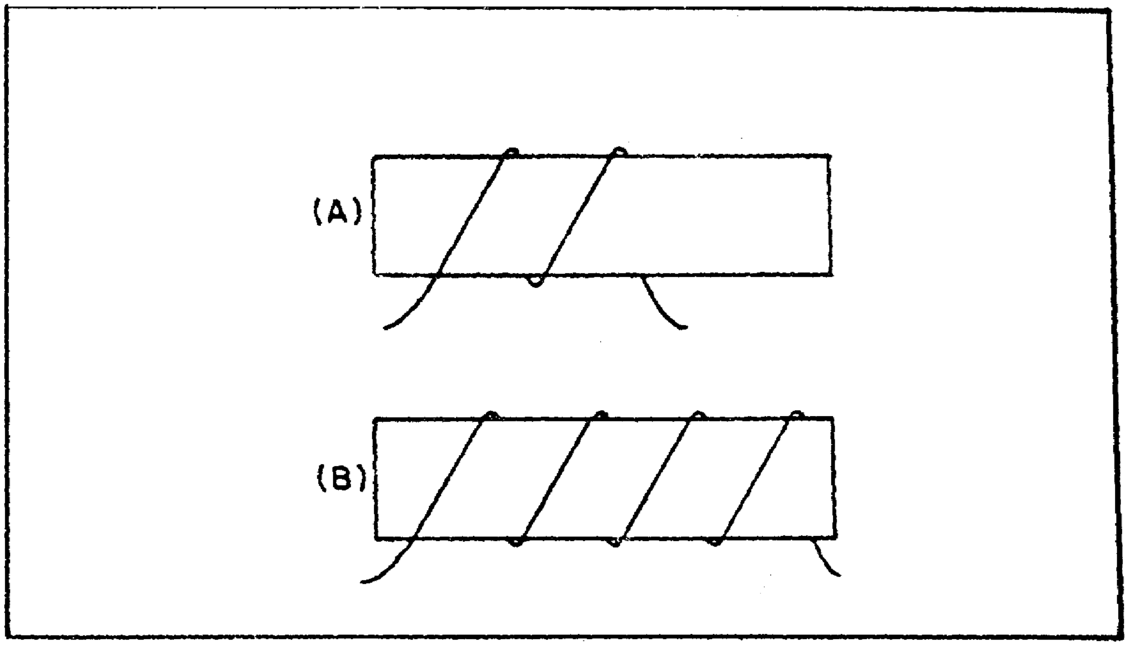


FIGURE 15. INDUCTANCE FACTOR (TURNS).

(b) *Coil Diameter*. The second factor is the coil diameter. Figure 1.6 on the following page shows a coil. (B) which has twice the diameter of coil (A). Physically, it. requires more wire to construct a coil of large diameter than one of small diameter with an equal number of turns. Therefore, more lines of force exist to induce a counter emf in the coil with the larger diameter. Actually, the inductance of a coil <u>increases directly as the cross-sectional area of the core increases</u>. Doubling the radius of a coil increases the inductance by a factor of four.

(c) *Length of the Coil*. The third factor that affects the inductance of a coil is the length of the coil. Figure 17 on page 26 shows two examples of coil spacings. Coil (A) has three turns, rather widely spaced, making a relatively long coil. A coil of this type has few flux linkages due to the greater distance between each turn. Therefore, coil (A) has a relatively low inductance. Coil (B) has closely spaced turns, making a relatively short coil. This close spacing increases the flux linkage, increasing the inductance of the coil. <u>Doubling the length of a coil while keeping the number of turns the same halves the inductance</u>.

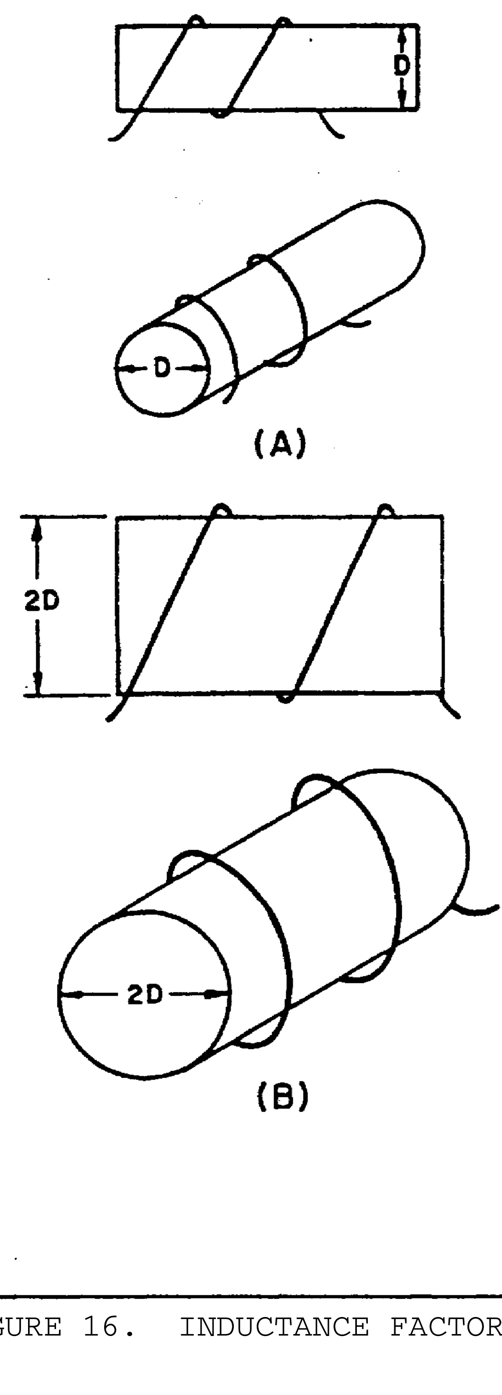


FIGURE 16. INDUCTANCE FACTOR (DIAMETER).

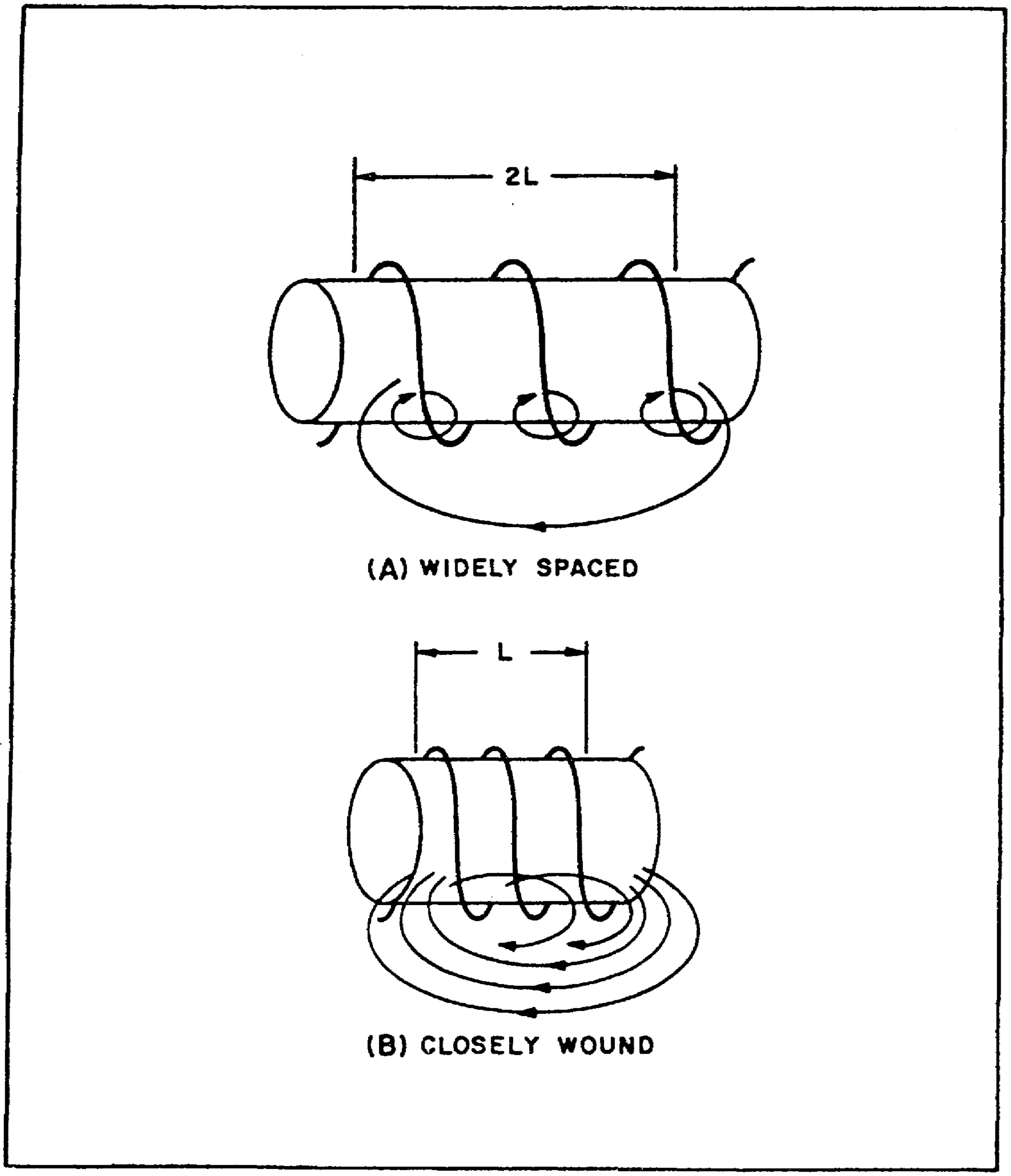


FIGURE 17. INDUCTANCE FACTOR (COIL LENGTH).

(d) *Type of Core Material*. The fourth physical factor is the type of core material used with the coil. Figure 18 on the following page shows two coils: coil (A) with an air core, and coil (B) with a soft-iron core. The magnetic core of coil (B) is a better path for magnetic lines of force than is the nonmagnetic core of coil (A). The soft-iron magnetic core's high permeability has less reluctance to the magnetic flux, resulting in more magnetic lines of force. This increase in the magnetic lines of force increases the number of lines of force cutting each loop of the coil, thus increasing the inductance of the coil. It should now be apparent that the inductance of a coil increases directly as the permeability of the core material increases.

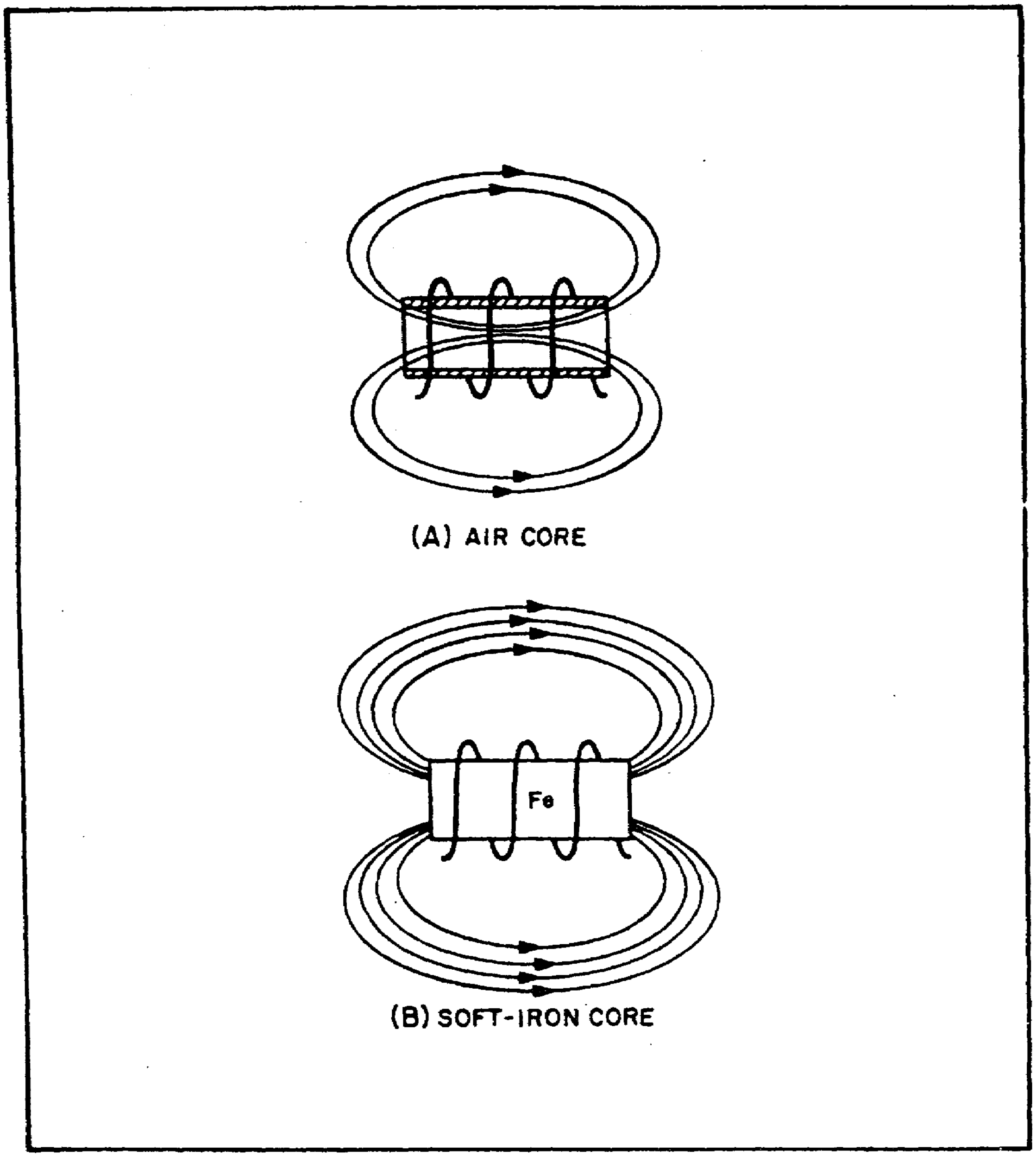


FIGURE 18. INDUCTANCE FACTOR (CORE MATERIAL).

(e) *Layering the Coils*. Another way of increasing the inductance is to wind the coil in layers. Figure 19 shows three cores with different amounts of 'layering. The coil in figure 19, view A, is a poor inductor compared to the others in the figure because its turns are widely spaced and there is no layering. The flux movement, indicated

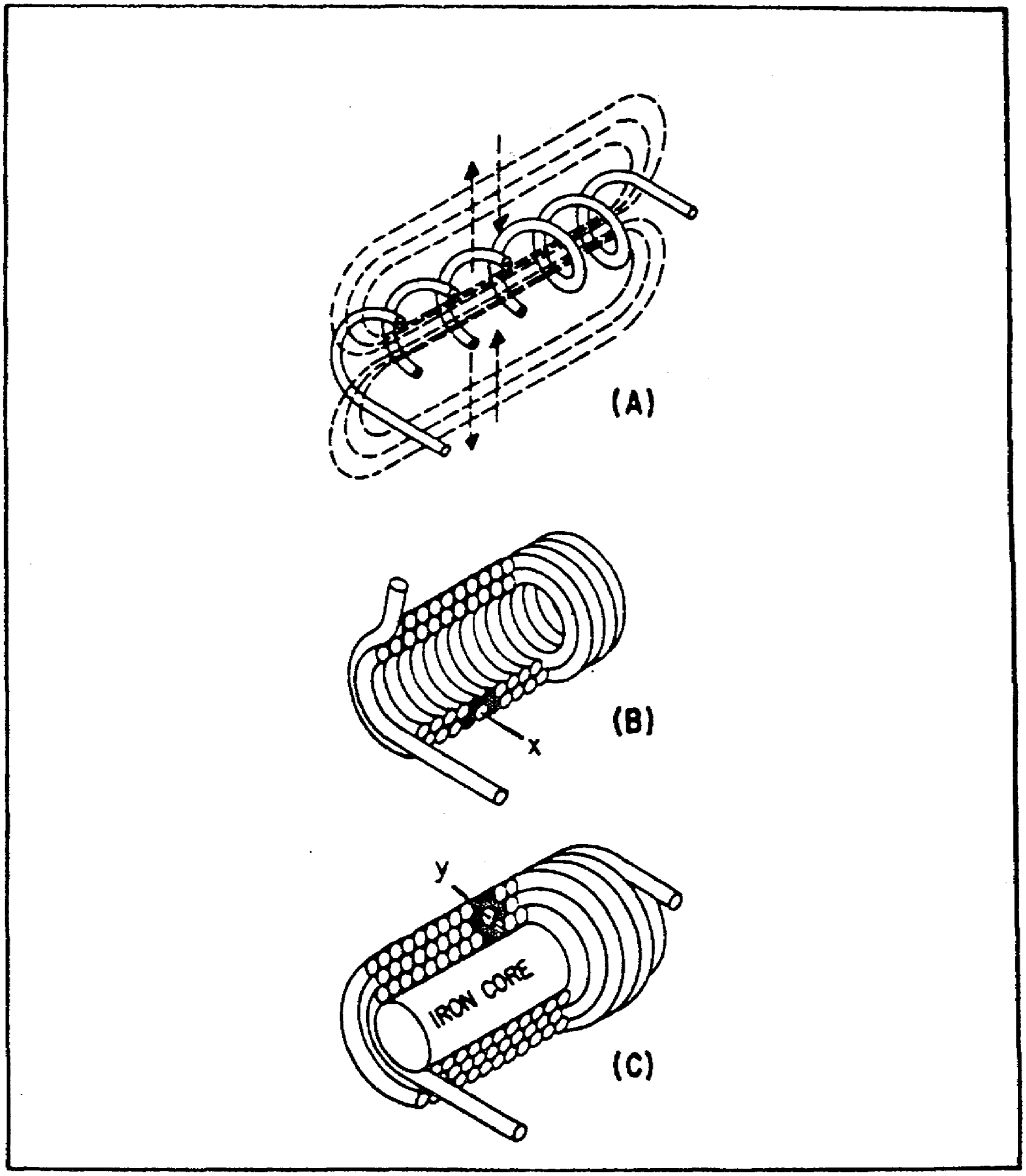


FIGURE 19. COILS OF VARIOUS INDUCTANCES.

by the dashed arrows, does not link effectively because there is only one layer of turns. A more inductive coil is shown in figure 19, view B (on the previous page). The turns are closely spaced and the wire has been wound in two layers. The two layers link each other with a greater number of flux loops during all flux movements, Note that nearly all the turns, such as X, are next to four other turns (shaded). This causes the flux .linkage to be increased.

A coil can be made still more inductive by winding it in three layers, as shown in figure 19, view C. The increased number of layers (cross-sectional area) improves flux linkage even more. Note that some turns, such as Y, lie directly next to six other turns (shaded). In actual practice, layering can continue on through many more layers. The important fact to remember, however, is that <u>the inductance of the coil increases with each layer added</u>.

As we have seen, several factors can affect the inductance of a coil, and all of these factors are variable. Many differently constructed coils can have the same inductance. The important thing to remember, however, is that <u>inductance is dependent upon the degree of link axe between the wire conductor(s) and the electromagnetic field</u>. In a straight length of conductor there is very little flux linkage between one part of the conductor and another. Therefore, its inductance is extremely small. It was shown that conductors become much more inductive when they are wound into coils. This is true because there is maximum flux linkage between the conductor turns, which lie side by side in the coil.

d. *Units of Inductance*. As stated before, the basic unit of inductance (L) is the HENRY (H), named after Joseph Henry, the co-discoverer with Faraday of the principle of electromagnetic induction. <u>An inductor has an inductance of 1 Henry if an emf of 1 volt is induced in the inductor when the current through the inductor is changing at the rate of 1 ampere per second</u>. The Henry is a large unit of inductance, and is used with relatively large inductors. With small inductors, the millihenry is used. A millihenry is equal to 1 x 10 Henry, and one Henry is equal to 1,000 millihenrys. For smaller inductors, the unit of inductance is the microhenry. A microhenry is

equal to 1 x 10^{-6} H, and one Henry is equal to 1,000,000 microhenrys.

e. *Growth and Decay of Current In An LR Series Circuit*. If a battery is connected across a pure inductance, the current builds up to its final value at a rate determined by the battery voltage and the internal resistance of the battery. The current buildup is gradual because of the counter emf generated by the self-inductance of the coil. When the current starts to flow, the magnetic lines of force move outward from the coil. These lines cut the turns of wire on the inductor and build up a counter emf that opposes the emf of the buttery. This opposition causes a delay in the time it takes the current to build up to a steady value. When the battery is disconnected, the lines of force collapse. Again, these lines cut the turns of the inductor and build up an emf that tends to prolong the flow of current.

A voltage divider containing resistance and inductance may be connected in a circuit by means of a special switch, as shown in figure 20, view A, on the following page. Such a series arrangement is called an inductance resistance (LR) circuit.

When switch S_1 is closed (as shown), a voltage (E_s) appears across the voltage divider. A current attempts to flow, but the inductor opposes the current by building up a back emf that, at the initial instant, exactly equals the input voltage (E_S). This is the same as having two voltage sources of equal value and opposite polarity. With this condition, no current will flow. Because no current can flow, there is no voltage drop across resistor R. View B, figure 20, shows that all of the voltage is impressed across inductor L and no voltage appears across resistance R at the instant switch S_1 is closed.

As current starts to flow, a voltage (e_R) appears across R, and the voltage across the inductor is reduced by the same amount. The fact that the voltage across the inductor (L) is reduced means that the growth current (i_g) is increased and consequently e_R is increased. View B, figure 20, shows that the voltage across the inductor (e_L) finally becomes zero when the growth current i_g) stops increasing, while the voltage across the resistor (e_R) builds up to a value equal to the source voltage (E_S).

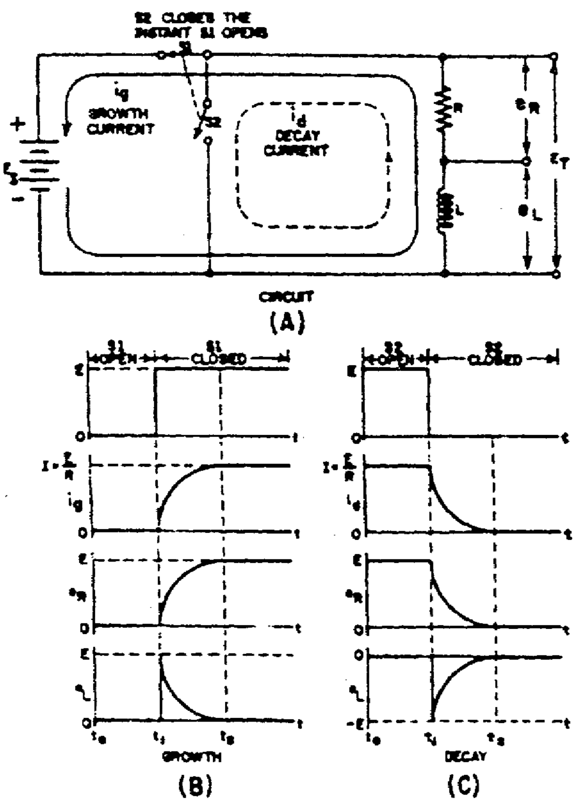


FIGURE 20. GROWTH AND DECAY OF CURRENT IN AN LR SERIES CIRCUIT.

Electrical inductance is like mechanical inertia, and the growth of current in an inductive circuit can be likened to the acceleration of a boat on the surface of water. The boat does not move at the instant a constant force is applied to it. At this instant, all the applied force is used to overcome the inertia of the boat. Once the inertia is overcome, the boat will start to move. After a while, the speed of the boat reaches its maximum value, and the applied force is only used in overcoming the friction of the water against the hull.

When the battery switch (S_1) in the LR circuit of figure 20, view A, is closed, the rate of current increase is maximum in the inductive circuit. At this instant, all the battery voltage is used in overcoming the emf of self-induction, which is at maximum because the rate of change of current is maximum. Thus the battery voltage is equal to the drop across the inductor, and the voltage across the resistor is zero. As time goes on, more of the battery voltage appears across the resistor and less across the inductor. The rate of change of current is approached, the drop across the inductor approaches zero, and all of the battery voltage is used to overcome the resistance of the circuit.

Thus, the voltages across the inductor and the resistor change in magnitude during the period of growth of current in the same way the force applied to the boat divides itself between the inertia and friction effects. The force is developed first. across the inertia/inductive effect and finally across the friction/resistive effect.

When switch S_2 is closed (source voltage E_s removed from the circuit), the flux that has been established around the inductor (L) is essentially equal to E_s in magnitude. The induced voltage causes decay current (i_d) to flow in resistor R in the same direction in which current was flowing originally (when S_1 was closed). A voltage (e_R) that is initially equal to source voltage (E_s) is developed across I. The voltage across the resistor (e_R) rapidly falls to zero as the voltage across the inductor (e_L) falls to zero due to the collapsing flux.

Just as the example of the boat was used to explain the growth of current in a circuit, it can also be used to explain the decay of current in a circuit. When the force applied to the boat is removed, the boat. continues to move through the water before eventually coming to a stop. This is because energy was being stored in the inertia of the moving boat. After a period of time, the friction of the water overcomes the inertia of the boat and the boat stops moving. Just as inertia of the boat stored energy, the magnetic field of an inductor stores energy. Because of this, even when the power source is removed, the stored energy of the magnetic field of the inductor tends to keep the current flowing in the circuit until the magnetic field collapses.

(1) *L/R Time Constant*. The L/R TIME CONSTANT is a variable tool for use in determining the time required for current in an inductor to reach a

specific value. As shown in figure 21, one L,/R time constant is the time required for the current in an inductor to increase to 63% (actually 63.2%) of the maximum current. Each time constant is equal to the time required for the current to increase by 63.2% of the difference in value between the current flowing in the inductor and the maximum current. Maximum current flows in the inductor after five L/R time constants are completed. The following example should clear up any confusion about time constants. Assume that the maximum current in an LR circuit is 10 amperes. As you know, when the circuit is energized, it takes time for the current to go from zero to 10 amperes.

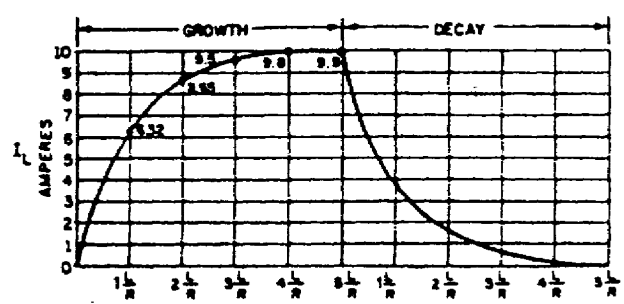


FIGURE 21. L/R TIME CONSTANT.

(a) When the first time constant is completed, the current in the circuit is equal to 63.2% (.632) of 10 amperes. Thus the amplitude of current at the end of 1 time constant is 6.32 amperes.

(b) During the second time constant, current again increases by 63.2% (.632) of the difference in value between the current flowing in the inductor and the maximum current. This difference is 10 amperes minus 6.32 amperes, and equals 3.68 amperes; 63.2% of 3.68 amperes is 2.32 amperes. This increase in current during the second time constant is added to that of the first time constant. Thus, upon completion of the second time constant, the amount of current in the LR circuit is 6.32 amperes + 2.32 amperes = 8.64 amperes.

(c) During the third constant, current again increases:

10 amperes - 8.64 amperes = 1.36 amperes

1.36 amperes x .632 = 0.860 ampere

8.64 amperes + 0.860 ampere = 9.50 amperes

(d) During the fourth time constant, current again increases:

10 amperes - 9.50 amperes = 0.5 ampere

0.5 ampere x .632 = 0.316 ampere

9.50 amperes + 0.316 ampere = 9.82 amperes

(e) During the fifth time constant, current increases as before:

10 amperes - 9.82 amperes = 0.18 ampere

0.18 ampere x .632 = 0.114 ampere

9.82 amperes + .114 ampere = 9.93 amperes

Thus, the current at the end of the fifth time constant is almost equal to 10.0 amperes, the maximum current. For all practical purposes, the slight difference in value can be ignored.

(2) *Deenergization of an LR Circuit*. When an LR circuit is deenergized, the circuit decreases (decays) to zero in five time constants at the same rate that it previously increased. If the growth and decay of current in an LR circuit are plotted on a graph, the curve appears as shown in figure 21 on the previous page. Notice that the current increases and decays at the same rate in five time constants.

The value of the time constant in seconds is equal to the inductance in Henrys divided by the circuit resistance in Ohms.

The formula used to calculate one $\frac{L}{R}$ time constant is:

$$t \text{ (in seconds)} = \frac{L \text{ (in Henrys)}}{R \text{ (in Ohms)}}$$

f. *Power Loss in an Inductor*. Since an inductor (coil) consists of a number of turns of wire, and since all wire has some resistance, every inductor has a certain amount of resistance. Normally this resistance is small. It is usually neglected in solving various types of ac circuit problems because the reactance of the inductor (the opposition to alternating current, which will be discussed later) is so much greater than the resistance that the resistance has a negligible effect on the current.

(1) *Copper Loss*. However, since some inductors are designed to carry relatively large amounts of current, considerable power can be dissipated in the inductor even though the amount of resistance in the inductor is small. This power is wasted power and is called COPPER LOSS. The copper loss of an inductor can be calculated by multiplying the square of the current in the inductor by the resistance of the winding (I^2R).

(2) *Iron Losses*. In addition to copper loss, an iron-core coil (inductor) has two iron losses. These are called HYSTERESIS LOSS and EDDY-CURRENT LOSS. Hysteresis loss is due to power that is consumed in reversing the magnetic field of the inductor core each time the direction of current in the inductor changes.

Eddy-current loss is due to currents that are induced in the iron core by the magnetic field around the turns of the coil. These currents are called eddy currents and flow back and forth in the iron core.

All these losses dissipate power in the form of heat. Since this power cannot be returned to the electrical circuit, it is lost power.

g. *Mutual Inductance*. Whenever two coils are located so that the flux from one coil links with the turns of the other coil, a change of flux in one coil causes an emf to be induced in the other coil. This allows the energy from one coil to be transferred or coupled to the other coil. The two coils are said to be coupled or linked by the property of MUTUAL INDUCTANCE. The amount of mutual inductance depends on the relative positions of the two coils. This is shown in figure 22 on the following page. If the coils are separated a considerable distance, the amount of

flux common to both coils is small, and the mutual inductance is low. Conversely, if the coils are close together so that nearly all the flux of one coil links the turns of the other, the mutual inductance is high. The mutual inductance can be increased greatly by mounting the coils on a common iron core.

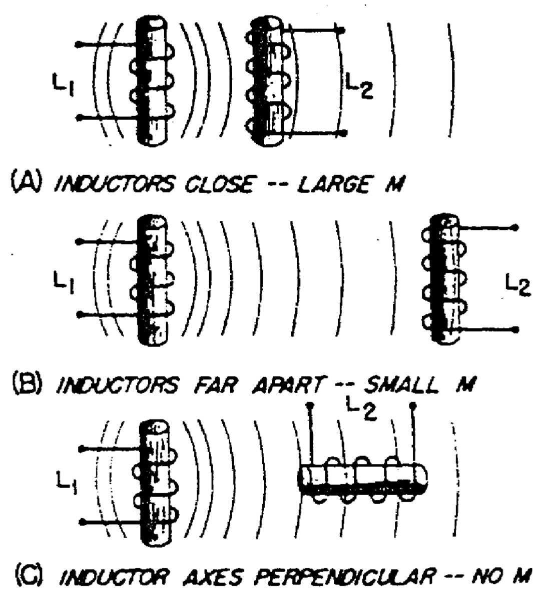


FIGURE 22. THE EFFECT OF POSITION OF COILS ON MUTUAL INDUCTANCE.

Two coils are placed close together as shown in figure 23 on the following page. Coil I is connected to a battery through switch S, and coil 2 is connected to an ammeter (A). When switch S is closed, as in figure 23, view A, the current that flows in coil I sets up a magnetic field that links with coil 2, causing induced voltage in coil 2 and a momentary deflection of the ammeter. When the current in coil 1 reaches a steady value, the ammeter returns to zero. If switch S is now opened as in figure 23, view B, the ammeter (A) deflects momentarily in the opposite direction, indicating a momentary flow of current in the opposite direction in coil 2. This current in coil 2 is produced by the collapsing magnetic field of coil 1.

(1) *Factors Affecting Mutual Inductance*. The mutual inductance of two adjacent coils is dependent upon the physical dimensions of the two coils, the number of turns in each coil, the distance between the two coils, the relative positions of the axes of the two coils, and the permeability of the core.

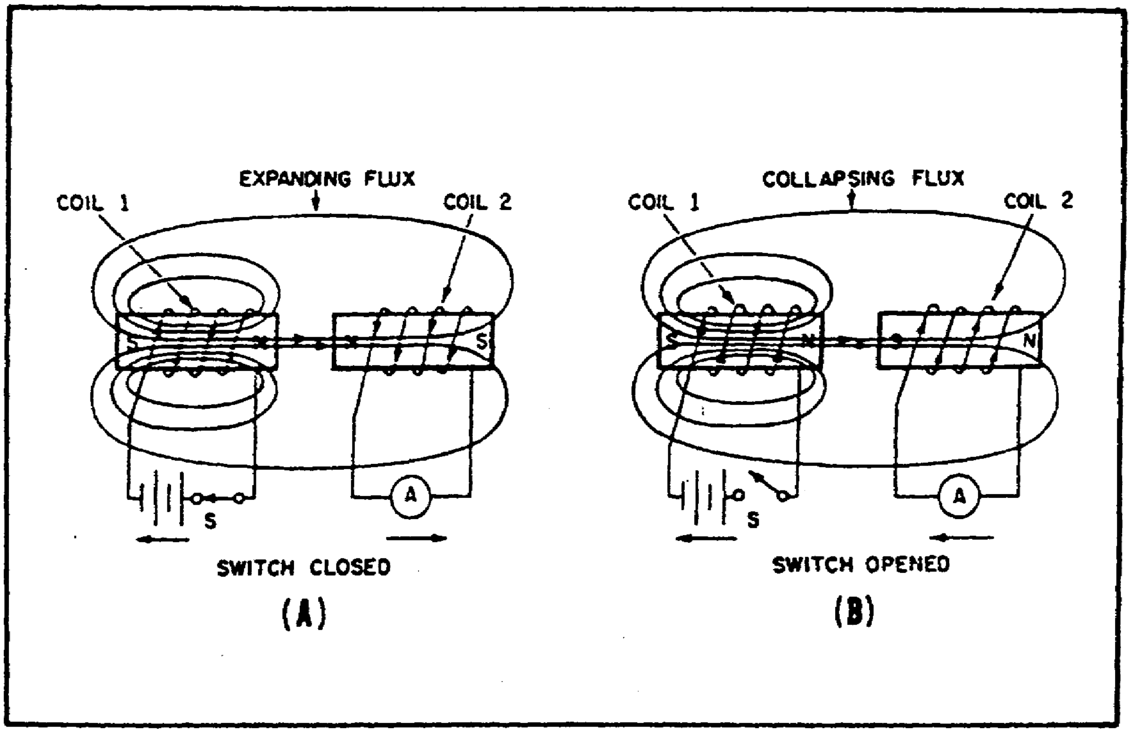


FIGURE 23. MUTUAL INDUCTANCE.

(2) *Coefficient of Coupling*. The COEFFICIENT OF COUPLING between the two coils is equal to the ratio of the flux cutting one coil to the flux originated in the other coil. If the two coils are so positioned with respect to each other that all of the flux of one coil cuts all the turns of the other, the coils are said to have a unity coefficient of coupling. It is never exactly equal to unity--one, but it approaches this value in certain types of coupling devices. If all the flux produced by one coil cuts only half the turns of the other coil, the coefficient of coupling is 0.5. The coefficient of coupling is designated by the letter K.

The mutual inductance between two coils, L_1 and L_2, is expressed in terms of the inductance of each coil and the coefficient of coupling K. As a formula:

$$M = \sqrt{K\ L_1\ L_2}$$

Where: M = Mutual inductance in henrys
K = Coefficient of coupling
L_1, L_2 = Inductance of coils in Henrys

h. *Series Inductors Without Magnetic Coupling*. When inductors are well shielded or are located far enough apart from one another, the effect of mutual inductance is negligible. If there is no mutual inductance (magnetic coupling) and the inductors are connected in series, the total inductance is equal to the sum of the individual inductances. As a formula:

$$L_T = L_1 + L_2 + L_3 + \ldots L_n$$

where L_T is the total inductance; L_1, L_2, L_3 are the inductances of L_1, L_2, L_3; and L_n means that any number (n) of inductors may be used. The inductances of inductors in series are added together, like the resistance of resistors in series.

i. *Series Inductors With Magnetic Coupling*. When two inductors in series are so arranged that the field of one links the other, the combined inductance is determined as follows:

$$L_T = L_1 + L_2 \pm 2M$$

where: L_T = The total inductance
L_1, L_2 = The inductances of L_1, L_2
M = The mutual inductance between the two inductors

When the magnetic fields of the two inductors are aiding each other, as shown in figure 24 on the following page, the plus sign is used with M. When the magnetic field of the two inductors oppose each other, as shown in figure 25 on the following page, the minus sign is used with M. The factor 2M accounts for the influence of L_1 on L_2, and L_2 on L_1.

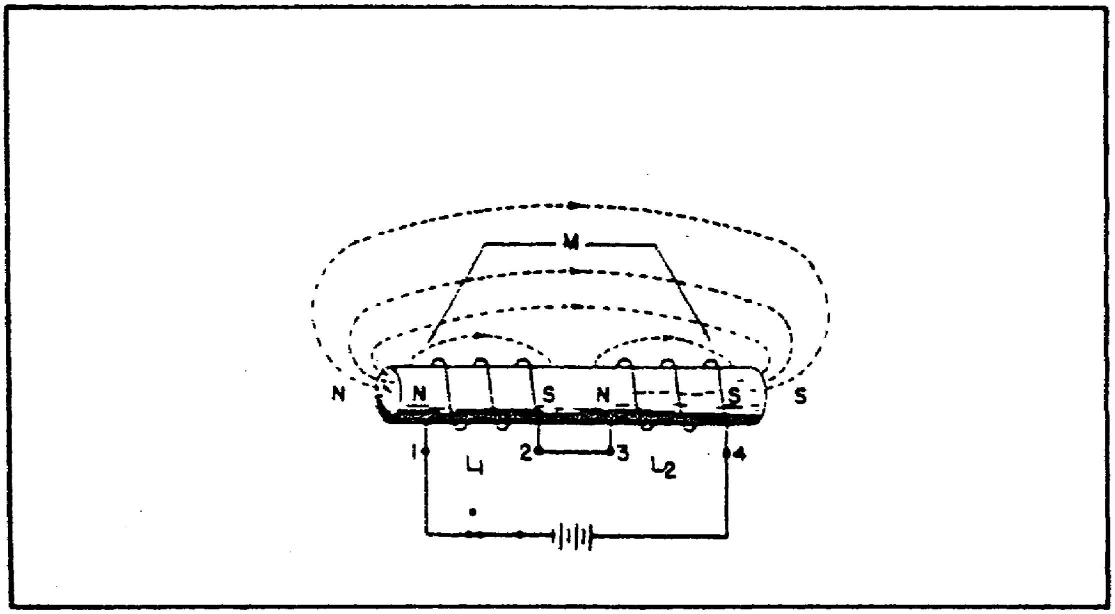


FIGURE 24. SERIES INDUCTORS WITH AIDING FIELDS.

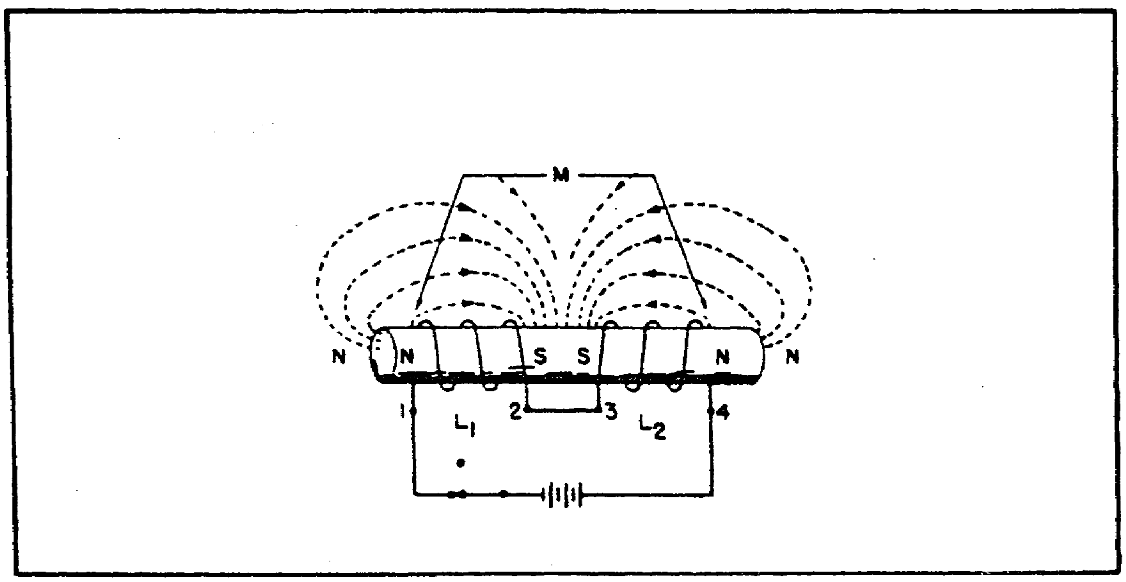


FIGURE 25. SERIES INDUCTORS WITH OPPOSING FIELDS.

j. Parallel Inductors Without Coupling. The total inductance (L_T) of inductors in parallel is calculated in the same manner that the total resistance of resistors in parallel is calculated, provided the coefficient of coupling between the coils is zero. Expressed mathematically:

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} \ldots . + \frac{1}{L_N}$$

4. Capacitance

Earlier it was learned that inductance is the property of a coil that causes energy to be stored in a magnetic field about the coil. The energy is stored in such a way as to oppose any change in current. CAPACITANCE is similar to inductance because it also causes a storage of energy. A CAPACITOR is a device that stores energy in an ELECTROSTATIC FIELD. The energy is stored in such a way as to oppose any change in voltage. Just how capacitance opposes a change in voltage will be explained later. However, it is first necessary to explain the principles of an electrostatic field as it is applied to capacitance.

a. *The Electrostatic Field*. It was previously learned that. opposite electrical charges attract each other while like electrical charges repel each other. The reason for this is the existence of an electrostatic field. Any charged particle is surrounded by invisible lines of force, called electrostatic lines of force. These lines of force have some interesting characteristics:

(1) They are polarized from positive to negative.

(2) They radiate from a charged particle in straight lines and do not form closed loops.

(3) They have the ability to pass through any known material.

(4) They have the ability to distort the orbits of tightly bound electrons.

Figure 26 on the following page represents two unlike charges surrounded by their electrostatic field. Because an electrostatic field is polarized from positive to negative, arrows are shown radiating away from the positive charge and toward the negative charge. Stated another way, the field from the positive charge is pushing, while the field from the negative charge is pulling. The effect of the field is to push and pull the unlike charges together.

In figure 27 on the following page, two like charges are shown with their surrounding electrostatic field. The effect of the electrostatic field is to push the charges apart.

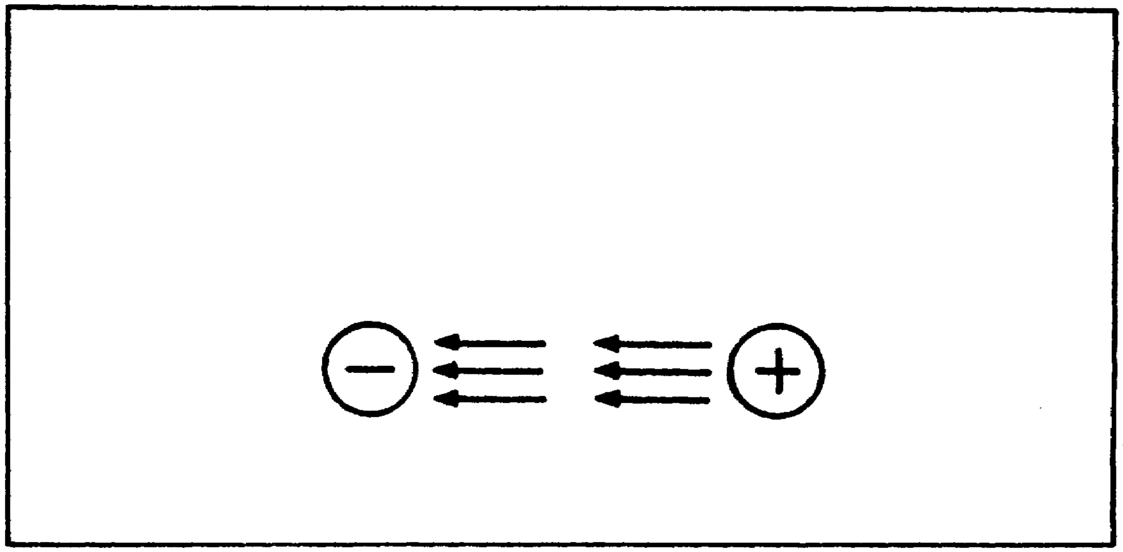


FIGURE 26. ELECTROSTATIC LINES OF FORCE SURROUNDING TWO UNLIKE CHARGED PARTICLES.

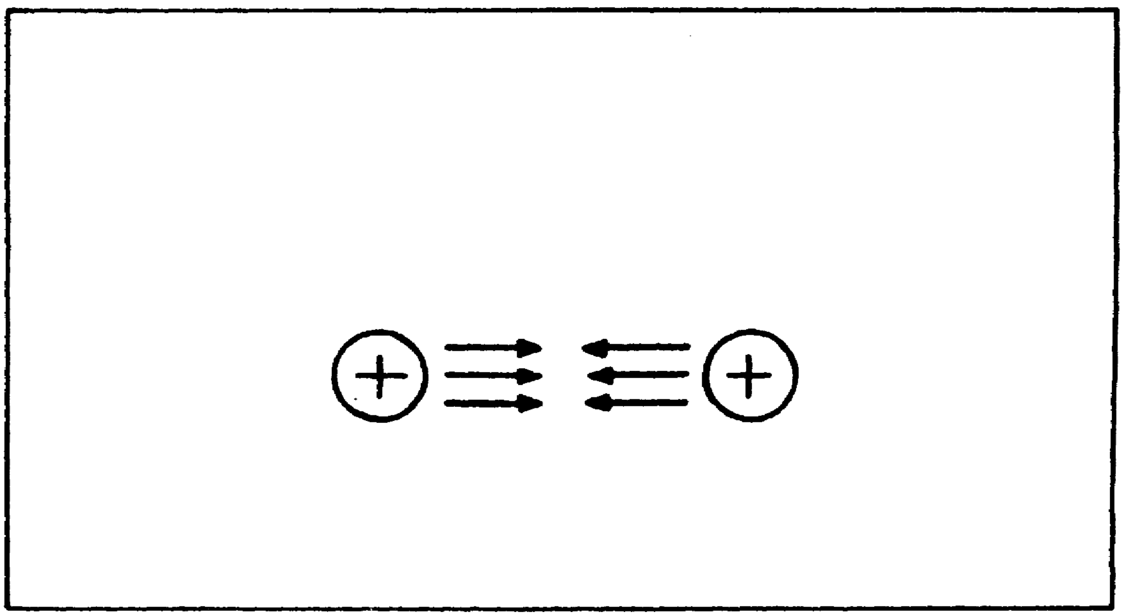


FIGURE 27. ELECTROSTATIC LINES OF FORCE SURROUNDING TWO LIKE CHARGED PARTICLES.

If unlike charges are placed on opposite sides of an atom whose outermost electrons cannot escape their orbits, the orbits of the electrons are distorted, as shown in figure 28 on the following page. Figure 28, view A, shows the normal orbit. View B of figure 28 shows the same orbit in the presence of charged particles. Since the electron is a negative charge, the positive charge attracts the electrons, pulling the electrons closer to the positive charge. The negative charge repels the electrons, pushing them further from the negative charge. It is this ability of an electrostatic field to attract and repel charges that allows the capacitor to store energy.

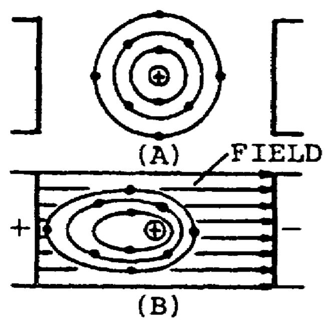


FIGURE 28. DISTORTION OF AN ELECTRON'S ORBIT DUE TO ELECTROSTATIC FORCE.

b. *The Simple Capacitor*. A simple capacitor consists of two metal plates separated by an insulating material called a dielectric, as illustrated in figure 29 on the following page. Note that one plate is connected to the positive terminal of a battery; the other plate is connected through a closed switch (S1) to the negative terminal of the battery. Remember, an insulator is a material whose electrons cannot easily 'escape their orbits. Due to the battery voltage, plate A is charged positively and plate B is charged negatively. Thus an electrostatic field is set: lip between the positive and negative plates. The electrons on the negative plate (plate B) are attracted to the positive charges on the positive plate (plate A).

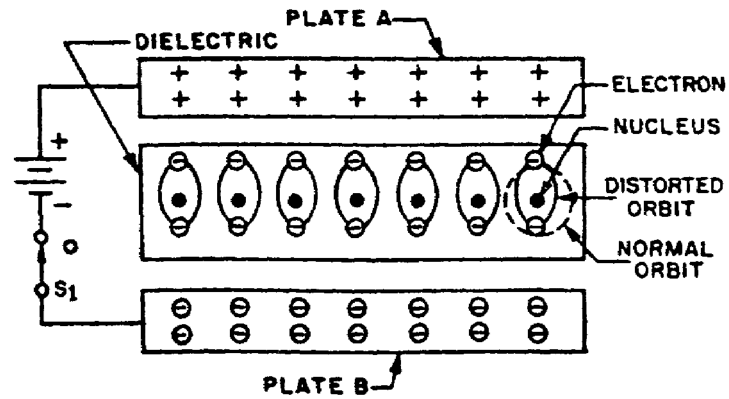


FIGURE 29. DISTORTION OF AN ELECTRON'S ORBITS IN A DIELECTRIC.

Notice that the orbits of the electrons in the dielectric material are distorted by the electrostatic field. The distortion occurs because the electrons in the dielectric are attracted to the top plate while being repelled from the bottom plate. When switch S1 is opened, the battery is removed from the circuit and the charge is retained by the capacitor. This occurs because the dielectric material is an insulator, and the electrons in the bottom plate (negative charge) have no path to reach the top plate (positive charge). The distorted orbits of the atoms of the dielectric, plus the electrostatic force of attraction between the two plates, hold the positive and negative charges in their original position. Thus, the energy which came from the battery is now stored in the electrostatic field of the capacitor.

Two slightly different symbols for representing a capacitor are shown in figure 30 on the following page. Notice that each symbol is composed of two plates separated by a space that represents the dielectric. The curved plate in view B of figure 30 indicates the plate should be connected to a negative polarity.

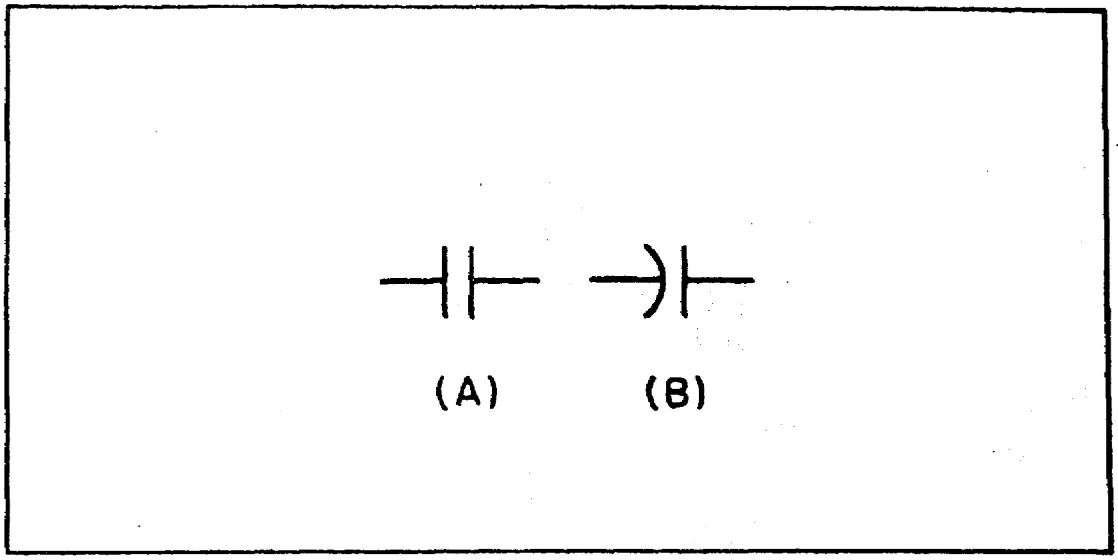


FIGURE 30. CIRCUIT SYMBOLS FOR CAPACITORS.

c. *The Farad*. Capacitance is measured in units called FARADS. A one-farad capacitor stores one coulomb (a unit of charge (Q) equal to 6.28 x 10^{18} electrons) of charge when a potential of 1 volt is applied across the terminals of the capacitor. This can be expressed by the formula:

$$C \text{ (farads)} = \frac{Q \text{ (coulombs)}}{F \text{ (volts)}}$$

The farad is a very large unit of measurement of capacitance. For convenience, the microfarad or the picofarad is used. One microfarad is equal to 0.000001 farad or 1 x 10^{-6} farad, and 1.0 picofarad is equal to 0.000000000001 farad or 1.0 x 10^{-12} farad. Capacitance is a physical property of the capacitor and does not depend on circuit characteristics of voltage, current, and resistance. A given capacitor always has the same value of capacitance (farads) in a circuit as in any other circuit in which it is connected.

d. *Factors Affecting the Value of Capacitance*. The value of capacitance of a capacitor depends on three factors: the area of the plates, the distance between the plates, and the dielectric constant of the material between the plates.

(1) *The Area of the Plates*. PLATE AREA affects the value of capacitance in the same manner that the size of a container affects the amount of water

that can he held by the container. A capacitor with the large plate area can store more charges than a capacitor with a small plate area. Simply stated, "the larger the plate area, the larger the capacitance."

(2) *The Distance Between the Plates*. The second factor affecting capacitance is the DISTANCE BETWEEN THE PLATES. Electrostatic lines of force are strongest when the charged particles that create them are close together. When the charged particles are moved further apart, the lines of force weaken, and the ability to store a charge decreases.

(3) *The Dielectric*. Constant of the Material Between the Plates. The third factor affecting capacitance is the DIELECTRIC CONSTANT of the insulating material between the plates of a capacitor. The various insulating materials used as the dielectric in a capacitor differ in their ability to respond to (pass) electrostatic lines of force. A dielectric material, or insulator, is rated as to its ability to respond to electrostatic lines of force in terms of a figure called the DIELECTRIC CONSTANT. A dielectric material with a high dielectric constant is a better insulator than a dielectric material with a low dielectric constant. Dielectric constants for some common materials are given in the following list:

Material	Constant
Vacuum	1.0000
Air	1.0006
Paraffin Paper	3.5
Glass	5 to 10
Mica	3 to 6
Rubber	2.5 to 35
Wood	2.5 to 8
Glycerin (15° C)	56
Petroleum	2
Pure Water	81

Notice the dielectric constant for a vacuum. Since a vacuum is the standard of reference, it is assigned a constant of one. The dielectric constants of all materials are compared to that of a vacuum. Since the dielectric constant of air has been determined to be approximately the same as a vacuum, the dielectric constant of AIR is also considered to be equal to one.

The formula used to compute the value of capacitance is:

$$C = 0.2249 \frac{(K\ A)}{d}$$

Where C = capacitance in picofarads
A = area of one plate, in square inches
d - distance between the plates, in inches
K = dielectric constant of the insulating material

0.2249 = a constant resulting from conversion from metric to British units.

Example: Find the capacitance of a parallel plate capacitor with paraffin paper as the dielectric.

Given: K = 3.5
d = 0.05 inch
A - 12 square inches

Solution: $$C = 0.2249 \frac{(K\ A)}{d}$$

$$C = 0.2249 \frac{(3.5 \times 12)}{0.005}$$

C = 189 picofarads

By examining the above formula it can be seen that capacitance varies directly as the dielectric constant and the area of the capacitor plates, and inversely as the distance between the plates.

e. *Voltage Rating of Capacitors*. In selecting or substituting a capacitor for use, consideration must be given to both the value of capacitance desired and the amount of voltage to be applied across the capacitor. If the voltage is too great, the dielectric will break down and arcing will occur between the capacitor plates. When this happens, the capacitor becomes a short-circuit and the flow of direct current through it can cause damage to other electronic parts. Each capacitor has a voltage rating (a working voltage) that should not be exceeded.

The working voltage of the capacitor is the maximum applied voltage that can be steadily applied without danger of breaking down the dielectric. The working voltage depends on the type of material used as the dielectric and on the thickness of the

dielectric. A high-voltage capacitor that has a thick dielectric must have a relatively large area in order to have the same capacitance as a similar low-voltage capacitor having a thin dielectric. The working voltage also depends on the applied frequency because the losses, and the resultant heating effect, <u>increase as the frequency increases</u>.

A capacitor that may be safely charged to 500 volts dc cannot be safely subjected to an alternating voltage or pulsating direct voltage having an effective value of 500 volts. Since an alternating voltage of 500 volts (root mean square, rms) has a peak value of 707 volts, a capacitor to which it is applied should have a working voltage of at least 750 volts. In practice, a capacitor should be selected so that its working voltage is at least 50 .percent greater than the highest effective voltage to be applied to it.

f. *Capacitor Losses*. Power loss in a capacitor may be attributed to dielectric hysteresis and dielectric leakage. Dielectric hysteresis may be defined as an effect in a dielectric material similar to the hysteresis found in a magnetic material. It is the result of changes in orientation of electron orbits in the dielectric because of the rapid reversals of the polarity of the line voltage. The amount of power loss due to dielectric hysteresis depends upon the type of dielectric used. A vacuum dielectric has the smallest power loss.

Dielectric leakage occurs in a capacitor as the result of leakage of current through the dielectric. Normally, it is assumed that the dielectric will effectively prevent the flow of current through the capacitor.-Although the resistance of the dielectric is extremely high, a minute amount of current does flow. Ordinarily this current is so small that, for all practical purposes, it is ignored. However, if the leakage through the dielectric is abnormally high, there will be a rapid loss of charge and an overheating of the capacitor.

The power loss of a capacitor is determined by loss in the dielectric. If the loss is negligible and the capacitor returns the total charge to the circuit, it is considered to be a perfect capacitor with a power loss of zero.

g. *Charging and Discharging a Capacitor.*

(1) *Charging.* In order to better understand the action of a capacitor in conjunction with other components, the charge and discharge actions of a purely capacitive circuit are analyzed first. For ease of explanation the capacitor and voltage source shown in figure 31 are assumed to be perfect (no internal resistance), although this is impossible in practice.

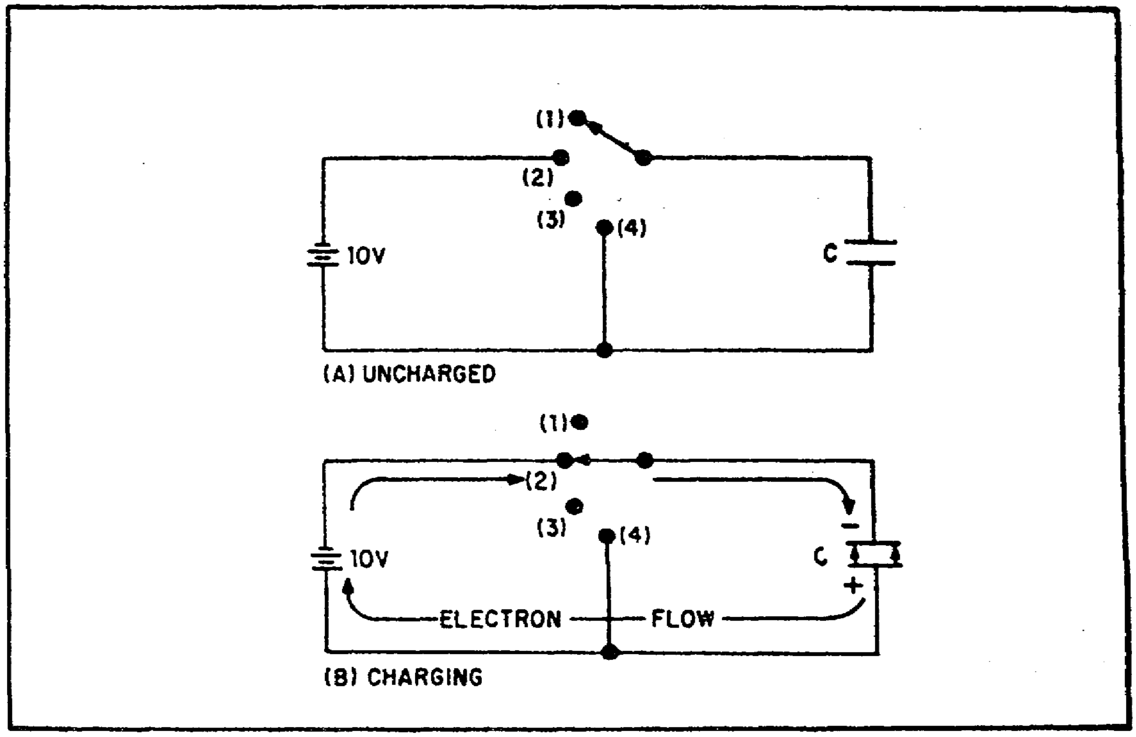


FIGURE 31. CHARGING A CAPACITOR.

In figure 31, view A, an uncharged capacitor is shown connected to a four-position switch. With the switch in position 1 the circuit is open and no voltage is applied to the capacitor. Initially each plate of the capacitor is a neutral body and until a difference of potential is impressed across the capacitor, no electrostatic field can exist between the plates.

To CHARGE the capacitor, the switch must be thrown to position 2, which places the capacitor across the terminals of the battery. Under the assumed perfect conditions, the capacitor would reach full charge instantaneously. However, the charging action is spread out over a period of time in the following discussion so that, a step-by-step analysis can be made.

At the instant the switch is thrown to position 2 (figure 31, view B, on the previous page), a displacement of electrons occurs simultaneously in all parts of the circuit. This electron displacement is directed away from the negative terminal and toward the positive terminal of the source (the battery). A brief surge of current will flow as the capacitor charges.

If it were possible to analyze the motion of the individual electrons in this surge of charging current, the following action would be observed (figure 32).

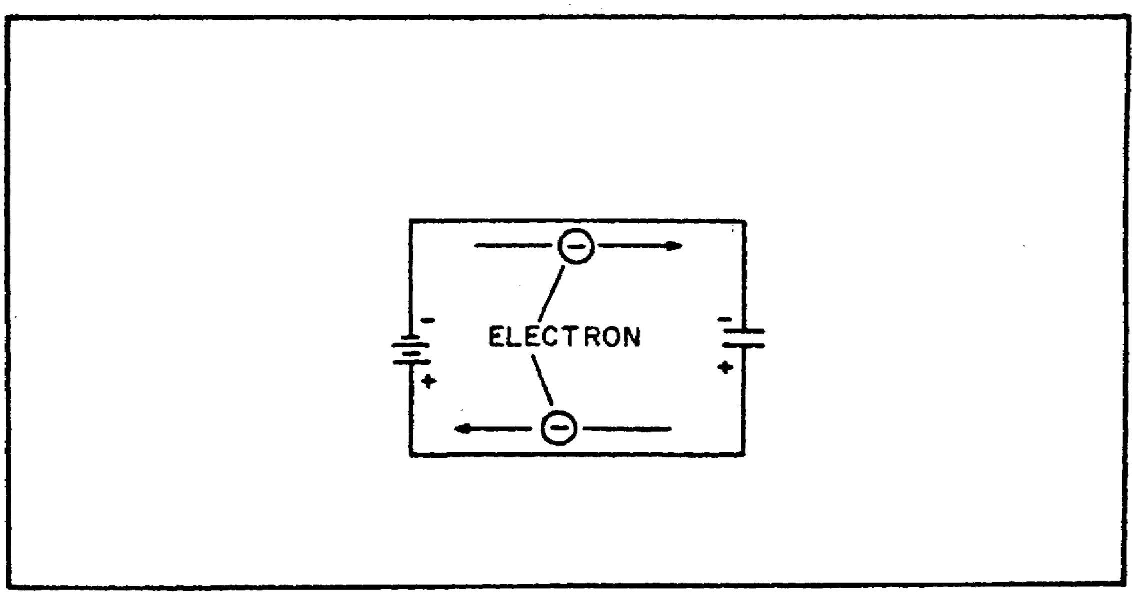


FIGURE 32. ELECTRON MOTION DURING CHARGE.

At the instant the switch is closed, the positive terminal of the battery extracts an electron from the bottom conductor. The negative terminal of the battery forces an electron into the top conductor. At this instant, an electron is forced into the top plate of the capacitor and another is pulled from the bottom plate. Thus, in every part of the circuit a clockwise DISPLACEMENT of electrons occurs simultaneously.

As electrons accumulate on the top of the capacitor and others depart from the bottom plate, a difference of potential develops across the capacitor. Each electron forced onto the top plate makes that plate more negative, while each electron removed from the bottom causes the bottom plate to become more positive. Notice that the polarity of the voltage which builds up across the capacitor is such as to oppose the source voltage. The source voltage (emf) forces current around the circuit' (figure 32 on the previous page in a clockwise direction. The emf developed across the capacitor, however, has a tendency to force the current in a counterclockwise direction, opposing the source emf. As the capacitor continues to charge, the voltage across the capacitor rises until it is equal to the source voltage. Once the capacitor voltage equals the source voltage, the two voltages balance one another and current ceases to flow in the circuit.

In studying the charging process of a capacitor, it must be noted that NO current flows THROUGH the capacitor. The material between the plates of the capacitor must be an insulator. However, to an observer stationed at the source or along one of the circuit conductors, the action has all the appearances of a true flow of current, even though the insulating material between plates of the capacitor prevents the current from having a complete path. The current which appears to flow through a capacitor is called DISPLACEMENT CURRENT.

When a capacitor is fully charged and the source voltage is equaled by the counter electromotive force (cemf) across the capacitor, the electrostatic field between the plates of the capacitor is maximum. Look again at figure 28 on page 42. Since the electrostatic field is maximum, the energy stored in the dielectric is called maximum.

If the switch is now opened, as shown in figure 33, view A, on the following page, the electrons on the upper plate are isolated. The electrons on the top plate are attracted to the charged bottom plate. Because the dielectric is an insulator, the electrons can not cross the dielectric to the bottom plate. The charges on both plates will be effectively trapped by the electrostatic field and the capacitor will remain charged indefinitely. It should be noted, at this point, that the insulating

dielectric material in a practical capacitor is not perfect and a small leakage of current will flow through the dielectric. This current will eventually dissipate the charge. However, a high quality capacitor may hold its charge for a month or more.

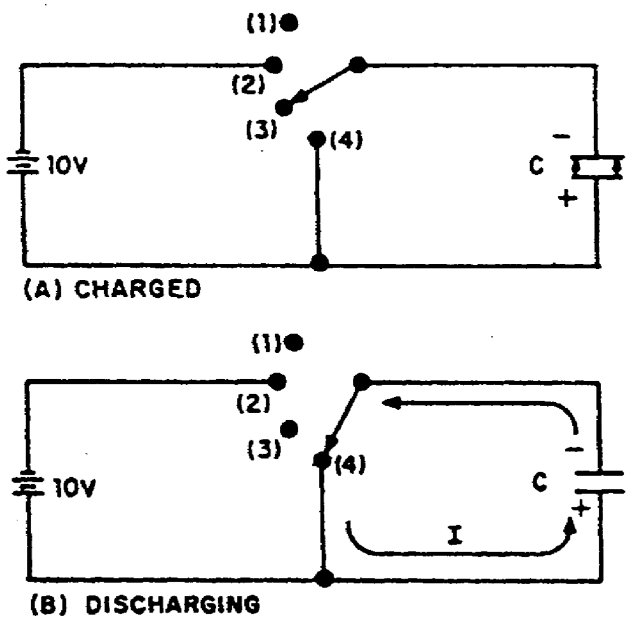


FIGURE 33. DISCHARGING A CAPACITOR.

To review briefly, when a capacitor is connected across a voltage source, a surge of charging current flows. This charging current develops a cemf across the capacitor which opposes the applied voltage. When the capacitor is fully charged, the cemf is equal to the applied voltage and charging current ceases. At full charge, the electrostatic field between the plates is at maximum intensity and the energy stored in the dielectric is maximum. If the charged capacitor is disconnected from the source, the charge will be retained for some period of time. The length of time the charge is retained depends on the amount of leakage current present. Since electrical energy is stored in the capacitor, a charged capacitor can act as a source emf.

(2) *Discharging*. To DISCHARGE a capacitor, the charges on the two plates must he neutralized. This is accomplished by providing a conducting path between the two plates as shown in figure 33, view B, on the previous page. With the switch in position (4), the excess electrons on the negative plate can flow to the positive plate and neutralize its charge. When the capacitor is discharged, the distorted orbits of the electrons in the dielectric return to their normal positions and the stored energy is returned to the circuit. It is important to note that a capacitor does not consume power. The energy the capacitor draws from the source is recovered when the capacitor is discharged.

h. *Charge and Discharge of a Resistance Capacitance (RC) Series Circuit*. Ohm's law states that the voltage across a resistance is equal to the current through the resistance times the value of the resistance. This means that a voltage is developed across a resistance ONLY WHEN CURRENT FLOWS through the resistance.

A capacitor is capable of storing or holding a charge of electrons. When uncharged, both plates of the capacitor contain essentially the same number of electrons. When charged, one plate contains more free electrons than the other plate. e difference in the number of electrons is a measure of the <u>charge</u> on the capacitor. The accumulation of this charge builds up a voltage across the terminals of the capacitor, and the charge continues to increase until this voltage equals the applied voltage. The <u>charge</u> in a capacitor is related to the capacitance and voltage as follows:

$$Q = CE,$$

in which Q is the charge in Coulombs, C the capacitance in farads, and E the emf across the capacitor in volts.

(1) Charge Cycle. A voltage divider containing resistance and capacitance is connected in a circuit by means of a switch, as shown at the top of figure 34 on the following page. Such a series arrangement is called an RC series circuit

In explaining the charge and discharge cycles of an RC series circuit, the time interval from time t_0 (time zero, when the switch is first closed) to

time T_1 (time one, when the capacitor reaches full charge or discharge potential will be used. Note that switches S1 and S2 move at the same time and can never be both closed at the same time.

When switch S1 of the circuit in figure 34 is closed at t_o, the source voltage (E_s) is instantly felt across the entire circuit. Graph A, figure 34, shows an instantaneous rise at time t_o from zero to source voltage (E_s = 6 volts). The total voltage can he measured across the circuit between points 1 and 2. Now look at figure 34, graph B, which represents the charging current in the capacitor (i_c). At time t_o, charging current is MAXIMUM. As time elapses forward time t_1, there is a continuous decrease in current flowing into the capacitor. The decreasing flow is caused by the voltage buildup across the capacitor. At time t_1 current flowing in the capacitor stops. At this time, the capacitor has reached full charge and has stored maximum energy in its electrostatic field. Figure 34, graph C, represents the voltage drop (e_r) across the resistor (R). The value of e_r is determined by the amount of current flowing

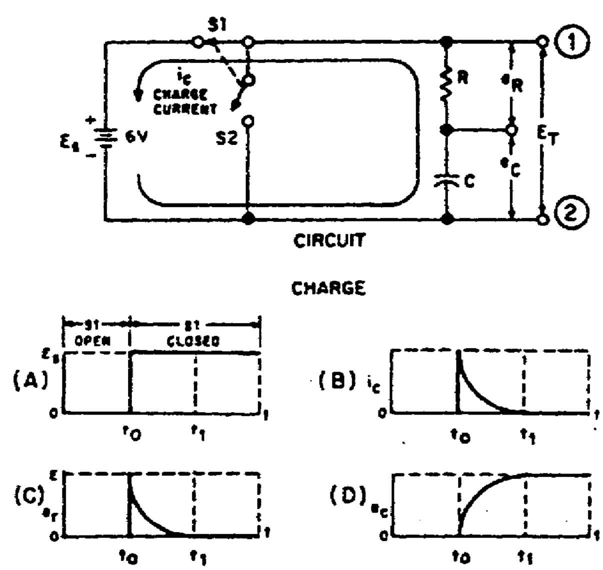


FIGURE 34. CHARGE OF AN RC SERIES CIRCUIT.

through the resistor on its way to the capacitor. At time t_0, the current flowing to the capacitor is maximum. Thus, the voltage drop across the capacitor is maximum (E=IR). As time progresses toward time t_1, the current flowing to the capacitor steadily decreases and causes the voltage developed across the resistor (R) to steadily decrease. When time t_1 is reached, current flowing to the capacitor is stopped, and the voltage developed across the resistor has decreased to zero.

It should be remembered that capacitance opposes a change in voltage. This is shown by comparing figure 34, graph A to graph D, on the previous page. In graph A, the voltage changed instantly from 0 volts to 6 volts across the circuit., while the voltage developed across the capacitor in figure 34, graph D took the entire time interval from t_0 to time t_1 to reach 6 volts. The reason for this is that In the first instant at time t_0, maximum current flows through R and the entire circuit voltage is dropped across the resistor. The voltage impressed across the capacitor at to is zero volts. As time progresses toward t_1, the decreasing current causes progressively less voltage to be dropped across the capacitor (C). At time t_1, the voltage across the capacitor is equal to the source voltage (6 volts), and the voltage dropped across the resistor (R) is equal to zero. This is the complete charge cycle of the capacitor.

As may have been noticed, the processes which take place in the time interval t_0 to t_1 in a series RC circuit are exactly opposite to those in a series LR circuit.

For comparison, the important points of the charge cycle of RC and LR series circuits are summarized in table 1 on the following page.

(2) *Discharge Cycle*. In figure 35 on page 56, at time t_0, the capacitor is fully charged. When S1 is open and S2 closes, the capacitor discharge cycle starts. At the first instant, circuit voltage attempts to go from source potential (6 volts) to zero volts, as shown in figure 35, graph A. Remember, though, the capacitor during the charge cycle has stored energy in an electrostatic field.

TABLE 1. SUMMARY OF CAPACITIVE AND INDUCTIVE CHARACTERISTICS.

		TIME ZERO (t_0)	TIME BETWEEN t_0 AND t_1	TIME ONE (t_1)
CIRCUIT CURRENT		MAXIMUM	DECREASING	ZERO
		ZERO	INCREASING	MAXIMUM
VOLTAGE DEVELOPED ACROSS THE RESISTOR		MAXIMUM	DECREASING	ZERO
		ZERO	INCREASING	MAXIMUM
VOLTAGE DEVELOPED ACROSS CAPACITOR/ INDUCTOR		ZERO	INCREASING	MAXIMUM
		MAXIMUM	DECREASING	ZERO

Because S2 is closed at. the same time S1 is open, the stored energy of the capacitor now has a path for the current to flow. At t_0 discharge current (i_d) from the bottom plate of the capacitor (C) is maximum. As time progresses toward t_1, the discharge current steadily decreases until, at time t_1, it reaches zero, as shown in graph B, figure 3 on the following page.

The discharge causes a corresponding voltage drop across the resistor as shown in figure 35, graph C. At time t_0, the current through the resistor is maximum and the voltage drop (e_r) across the resistor is maximum. As the current through the resistor decreases, the voltage drop across the

resistor decreases until at t_1 it has reached a value of zero. Graph D, figure 35, shows the voltage across the capacitor (e_c) during the discharge cycle. At time t_o, the voltage is maximum, and as time progresses toward time t_1, the energy stored in the capacitor is depleted. At the same time, the voltage across the resistor is decreasing, the voltage (e_c) across the capacitor is decreasing, until, at time t_1, the voltage (e_c) reaches zero.

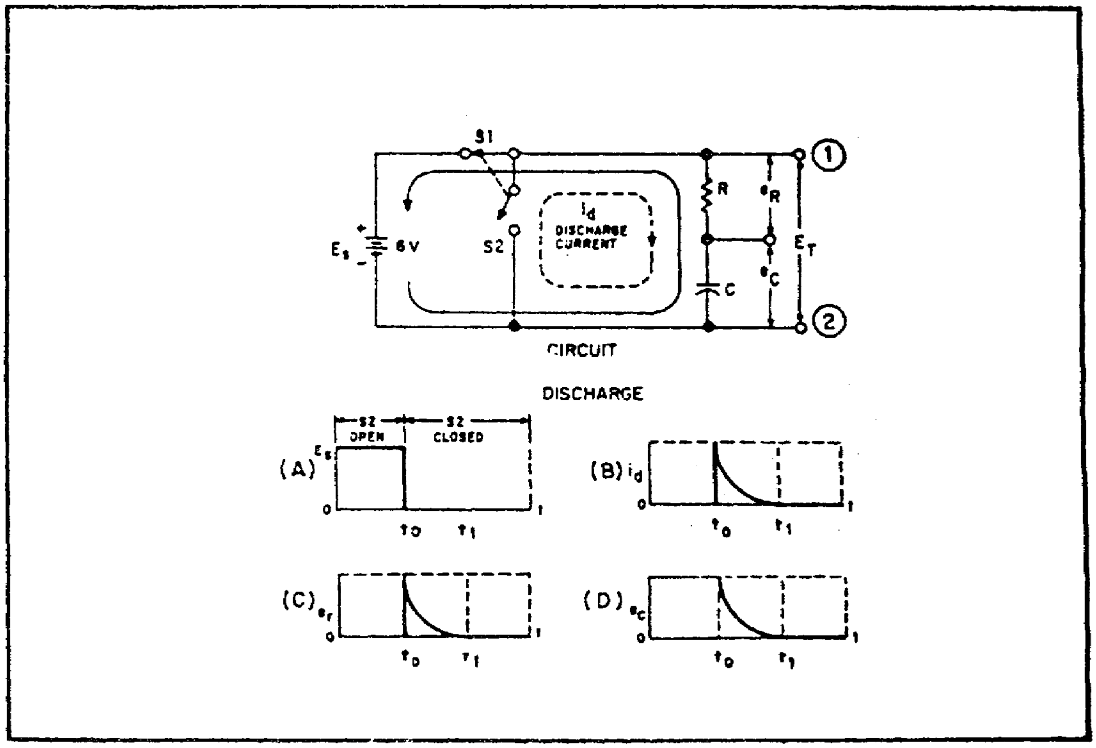


FIGURE 35. DISCHARGE OF AN RC SERIES CIRCUIT.

Comparison of graph A with graph D of figure 35 indicates the effect that capacitance has on a change in voltage. If the circuit had not contained a capacitor, the voltage would have cease at the instant S1 was opened at time t_o. Because the capacitor is in the circuit, voltage is applied to the circuit until the capacitor has discharge completely at t_1. The effect of capacitance has ten been to oppose this change in voltage.

i. *RC Time Constant*. The time required to charge a capacitor to 63% (actually 63.2%) of maximum voltage, or to discharge it to 37% (actually 36.8%) of its final voltage is known as the TIME CONSTANT (TC) of the circuit. The charge and discharge curves of a capacitor are shown in figure 36. Note that the charge curve is like the curve in figure 34, graph 1), on page 53, and the discharge curve like the curve in figure 34, graph B.

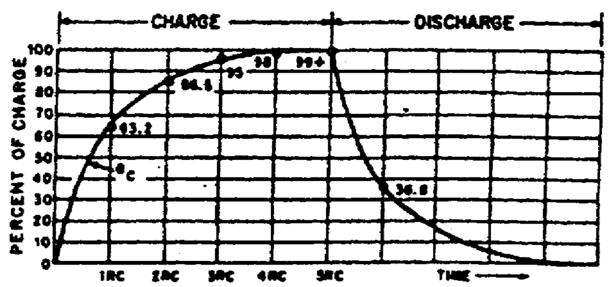


FIGURE 36. RC TIME CONSTANT.

The value of the time constant in seconds is equal to the product of the circuit resistance in Ohms and the circuit. capacitance in farads. The value of one time constant is expressed mathematically as t=RC. Some forms of this formula used in calculating RC time constants are:

t(in seconds) = R (in Ohms) x C(in farads)

t(in seconds) = R (in megohms) x C(in microfarads)

t(in microseconds) = R (in Ohms) x C(in microfarads)

t(in microseconds) = R (in megohms) x C(in picofarads)

j. *Universal Time Constant Chart*. Because the impressed voltage and the values of R and C or R and L, in a circuit are usually known, a UNIVERSAL, TIME CONSTANT CHART (figure 37 on the following page)can be used to find the time constant of the circuit. Curve A is a plot of both capacitor voltage during charge and inductor current. during growth. Curve B is a plot of both capacitor voltage during discharge and inductor current during decay.

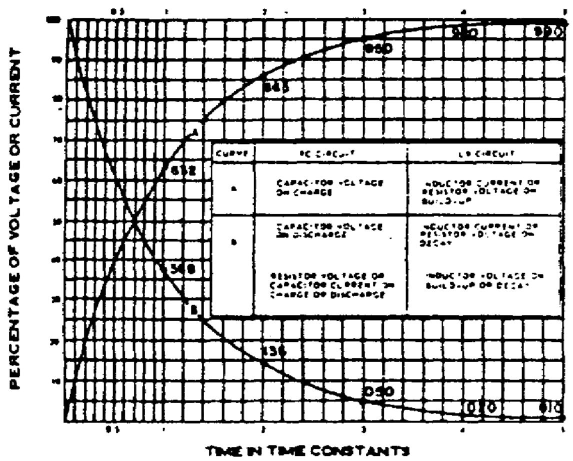


FIGURE 37. UNIVERSAL TIME CONSTANT CHART FOR RC AND RL CIRCUITS.

The time scale (horizontal scale) is graduated in terms of the RC or $\frac{L}{R}$ time constants so that the curves may be used for any value of R and C or I, and R. The voltage and current scales (vertical scales) are graduated in terms of percentage of maximum voltage or current so that the curves may be used for any value of voltage or current. If the time constant and the initial or final voltage for the circuit in question are known, the voltages across, the various parts of the circuit can be obtained from the curves for any time after the switch is closed, either on charge or discharge. The same reasoning is true for the current: in the circuit.

The following problem illustrates how the universal time constant chart may be used.

An RC circuit is to be designed in which a capacitor (C) must charge to 20% (0.20) of the maximum charging voltage in 100 microseconds (0.0001 second). Because of other considerations, the resistor (R) must have a value of 20,000 Ohms. What value of capacitance is needed?

Given: Percent of charge = 20% (0.20)
t = 100 microseconds
R = 20,000 Ohms

Find: The capacitance of capacitor C.

Solution: Because the only values given are in units of time and resistance, a variation of the formula to find RC time is used:

$$RC = R \times C$$

where: one RC time constant = R x C and R is known.

Transpose the formula to:

$$C = \frac{RC}{R}$$

Find the value of RC by referring to the universal time constant chart in figure 37, on the previous page, and proceed as follows:

(1) Locate the 20 point on the vertical scale at the left side of the chart (percentage).

(2) Follow the horizontal line from this point to intersect curve A.

(3) Follow an imaginary vertical line from the point of intersection on curve A downward to cross the RC scale at the bottom of the chart.

Note that the vertical line crosses the horizontal scale at about .22 RC as illustrated below (figure 38 on the following page).

The value selected from the graph means that a capacitor (including the one we are solving for) will reach twenty percent of full charge in twenty-two one hundredths (.22) of a single RC time constant. Remember that it takes 100 microseconds for the capacitor to reach 20% of full charge. Since 100 microseconds is equal to .22 RC (twenty-

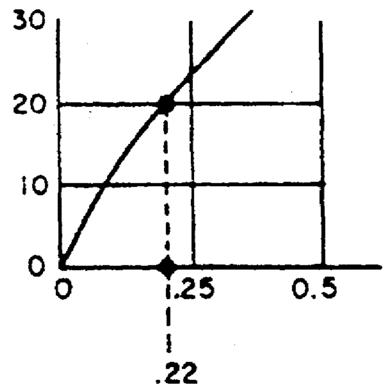


FIGURE 38. SOLUTION FOR UNIVERSAL TIME CONSTANT PROBLEM.

two one hundredths), then the time required to reach one RC time constant must be equal to:

$$.22\ RC = 100 \text{ microseconds}$$

$$RC = \frac{1 \times 100 \text{ microseconds}}{.22}$$

$$RC = \frac{100 \text{ microseconds}}{.22}$$

$$RC = 454.54 \text{ microseconds (rounded to 455 microseconds)}$$

$$RC = 455 \text{ microseconds}$$

Now use the following formula to find C:

$$C = \frac{RC}{R}$$

$$C = \frac{455 \text{ microseconds}}{20{,}000 \text{ Ohms}}$$

$$C = 0.0227 \text{ microfarads}$$

$$C = 0.023 \text{ microfarads}$$

To summarize the above procedures, the problem and solution are shown below without the step-by-step explanation.

Given: Percent of charge = 20% (.20)
T = 100 microseconds
R = 20,000 Ohms

Transpose the RC time constant formula as follows:

R x C = RC

$$C = \frac{RC}{R}$$

Find: HC

.22 RC = 100 microseconds

$$RC = \frac{100 \text{ microseconds}}{.22}$$

RC = 455 microseconds

Substitute the R and RC values into the formula:

$$C = \frac{RC}{R}$$

$$C = \frac{455 \text{ microseconds}}{20{,}000 \text{ Ohms}}$$

C = .023 microfarads

The graphs shown in figures 36 and 37 on pages .57 and 58, respectively, are not entirely correct. That is, the charge or discharge (growth or decay) will not quite complete in 5 RC or 5 $\frac{L}{R}$ time constants. However, when the values reach 0.99 of the maximum (corresponding to 5 RC or 5 $\frac{L}{R}$), the graphs may be considered accurate enough for all practical purposes.

k. *Capacitors in Series and Parallel*. Capacitors may be (connected in series or in parallel to obtain a resultant value which may be either the sum of the individual values (in parallel) or a value less than that of the smallest capacitance (in series).

(1) *Capacitors in Series*. The overall effect of connecting capacitors in series is to move the plates of the capacitors further apart. This is shown in figure 39 on the following page. Notice that the junction between C1 and C2 has both a negative and a positive charge. This causes the

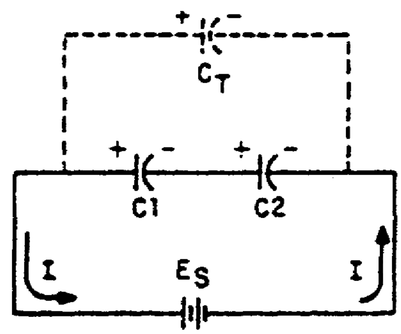


FIGURE 39. CAPACITORS IN SERIES.

junction to be essentially neutral. The total capacitance of the circuit is developed between the left plate of C1 and the right plate of C2. Because these plates are farther apart, the total value of the capacitance in the circuit is decreased. Solving for the total capacitance (C_T) of capacitors connected in series is similar to solving for total resistance (R_T) of resistors connected in parallel.

Note the similarity between the formulas for R_T and C_T:

$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \ldots \frac{1}{R_n}}$$

$$C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \ldots \frac{1}{C_n}}$$

For example, the value of three (3) 0.015 microfarad capacitors connected in series is 0.005 microfarads. If the circuit contains more than two capacitors, use the formula above. If the circuit contains only two capacitors, use the formula below:

$$C_T = \frac{C1 \times C2}{C1 + C2}$$

NOTE

All values for C_T, C1, C2, C3,...C_n should be in farads. It should be evident from the above formulas that the total capacitance of capacitors in series is less than the capacitance of any of the individual capacitors.

(2) *Capacitors in Parallel*. When capacitors are connected in parallel, one plate of each capacitor is connected directly to one terminal of the source, while the other plate of each capacitor is connected to the other terminal of the source. Figure 40 shows all the negative plates of the capacitors connected together, and all the positive plates connected together. C_T, therefore, appears as a capacitor with a plate area equal to the sum of all the individual plate areas. As previously mentioned, capacitance is a direct function of plate area. Connecting capacitors in parallel effectively increases plate area and thereby increases total capacitance.

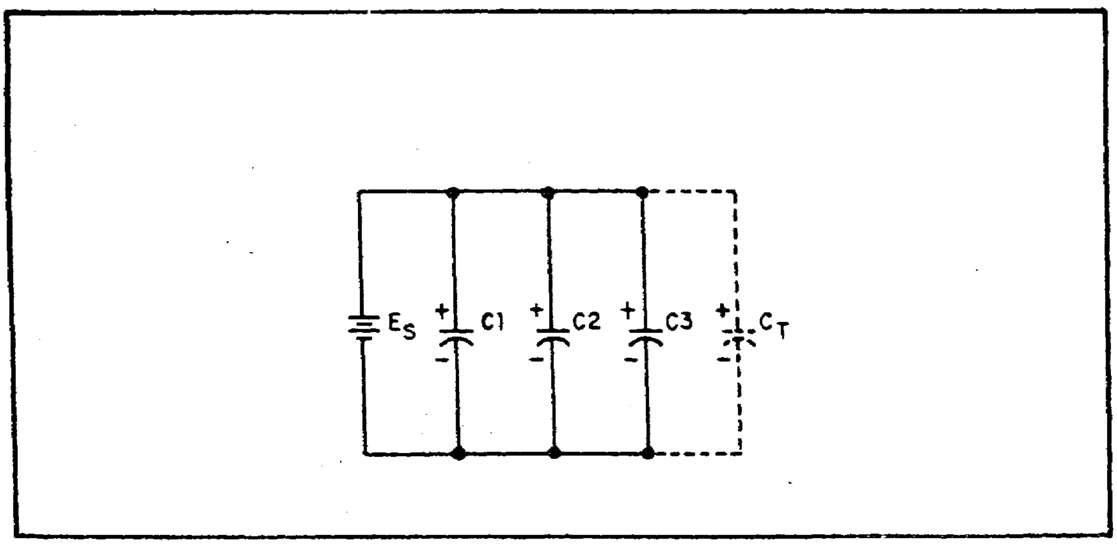


FIGURE 40. PARALLEL CAPACITIVE CIRCUIT.

For capacitors connected in parallel the total capacitance is the sum of all the individual capacitances. The total capacitance of the circuit may be calculated using the formula:

$$C_T = C1 + C2 + C3 + \ldots\ldots\ldots C_n$$

1. *Fixed Capacitors*. A fixed capacitor is constructed in such a manner that it possesses a fixed value of capacitance which cannot be adjusted. A fixed capacitor is classified according to the type of material used as its dielectric, such as paper, oil, mica, or electrolyte.

(1) Paper Capacitors. A PAPER CAPACITOR is made of flat think strips of metal foil conductors that are separated by waxed paper (the dielectric material). Paper capacitors usually range in value from about 300 picofarads to about 4 microfarads. The working voltage of a paper capacitor rarely exceeds 600 volts. Paper capacitors are sealed with wax to prevent the harmful effects of moisture and to prevent corrosion and leakage.

Many different kinds of outer coverings are used on paper capacitors, the simplest being a tubular cardboard covering. Some types of paper capacitors are encased in very hard plastic. These types are very rugged and can be used over a much wider temperature range than can the tubular cardboard type. Figure 41, view A, shows the construction of a tubular paper capacitor; figure 41, view B, shows a completed cardboard-encased capacitor.

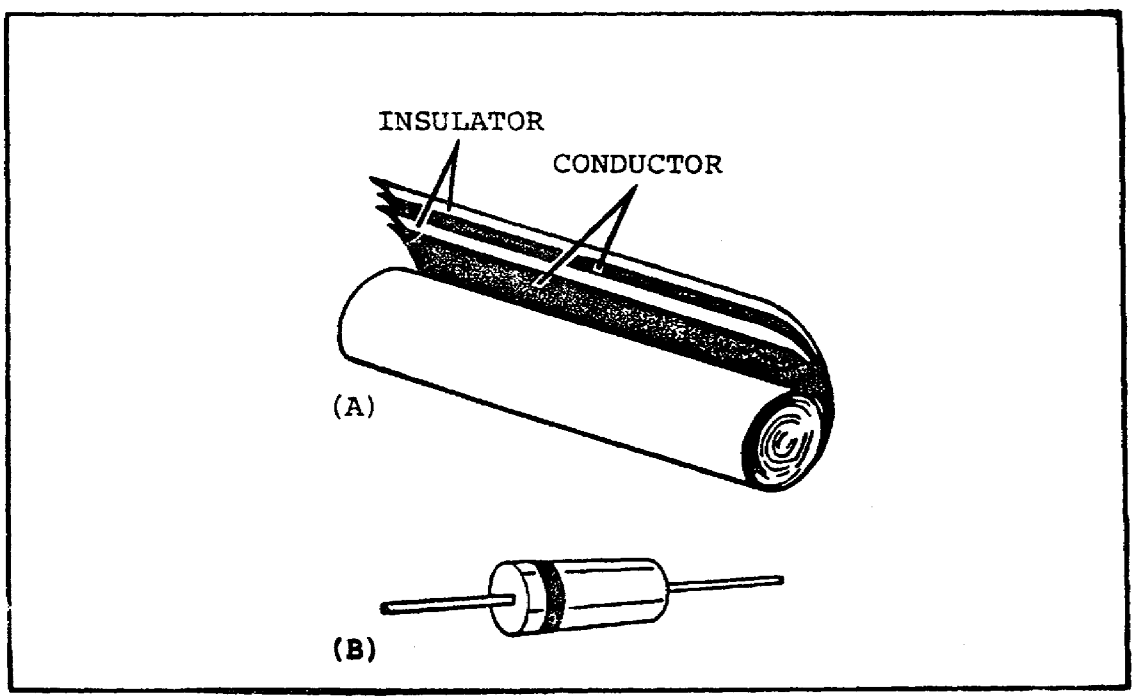


FIGURE 41. PAPER CAPACITOR.

(2) *Mica Capacitors*. A MICA CAPACITOR is made of metal foil plates that are separated by sheets of mica (the dielectric). The whole assembly is encased in molded plastic. Figure 42, view A, shows a cut-away view of a mica capacitor. Because the capacitor parts are molded into a plastic case, corrosion and damage to the plates and dielectric are prevented. In addition, the molded plastic case makes the capacitor mechanically stronger. Various types of terminals are used on mica capacitors to connect them into circuits. These terminals are also molded into the plastic case.

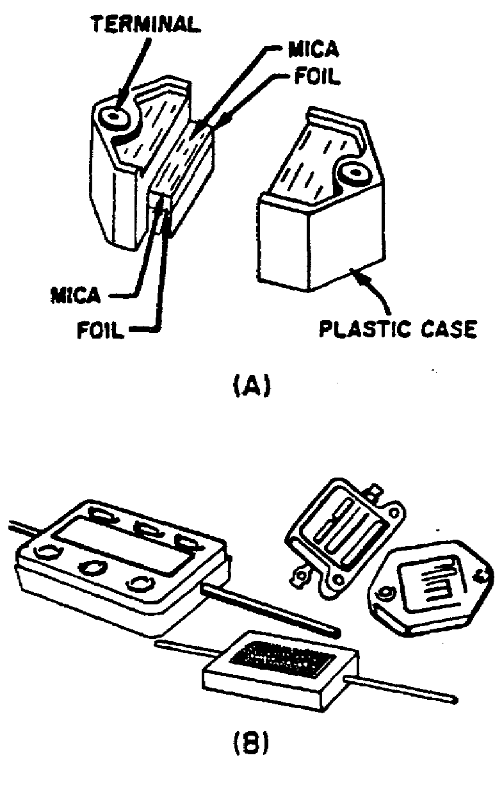


FIGURE 42. TYPICAL MICA CAPACITORS.

Mica is an excellent dielectric and can withstand a higher voltage than can a paper dielectric of the same thickness. Common values of mica capacitors range from approximately 50 picofarads to 0.02 microfarads. Some different shapes of mica capacitors are shown in figure 42, view B, on the previous page.

(3) *Ceramic Capacitors*. A CERAMIC CAPACITOR is so named because it contains a ceramic dielectric. One type of ceramic capacitor uses a hollow ceramic cylinder as both the form on which to construct the capacitor and as the dielectric material. The plates consist of thin films of metal deposited on the ceramic cylinder.

A second type of ceramic capacitor is manufactured in the shape of a disk. After leads are attached to each side of the capacitor, the capacitor is completely covered with an insulating moisture-proof coating. Ceramic capacitors usually range in value from 1 picofarad to 0.01 microfarad and may be used with voltages as high as 30,000 volts. Some different shapes of ceramic capacitors are shown in figure 43.

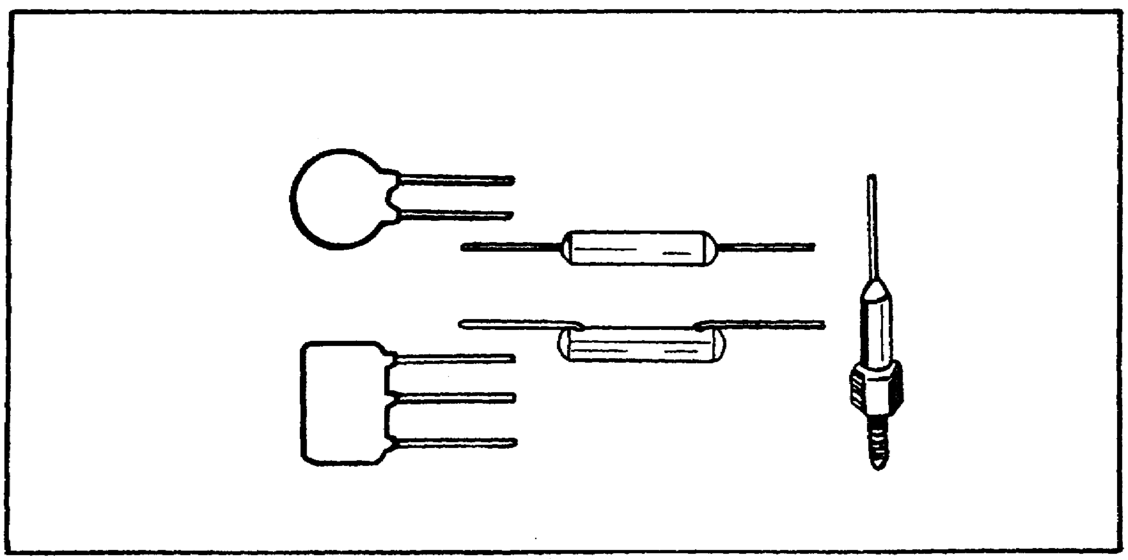


FIGURE 43. CERAMIC CAPACITORS.

(4) *Electrolytic Capacitors*. An ELECTROLYTIC CAPACITOR is used where a large amount of capacitance is required. As the name implies, an electrolytic capacitor contains an electrolyte. This electrolyte can be in the form of a liquid (wet electrolytic capacitor). The wet electrolytic

capacitor is no longer in popular use due to the care needed to prevent spilling of the electrolyte.

A dry electrolytic capacitor consists essentially of two metal plates separated by the electrolyte. In most cases the capacitor is housed in a cylindrical aluminum container which acts as the negative terminal of the capacitor (figure 44). The positive terminal (or terminals if the capacitor is of the multisection type) is a lug (or lugs) on the bottom end of the container. The capacitance value(s) and the voltage rating of the capacitor are generally printed on the side of the aluminum case.

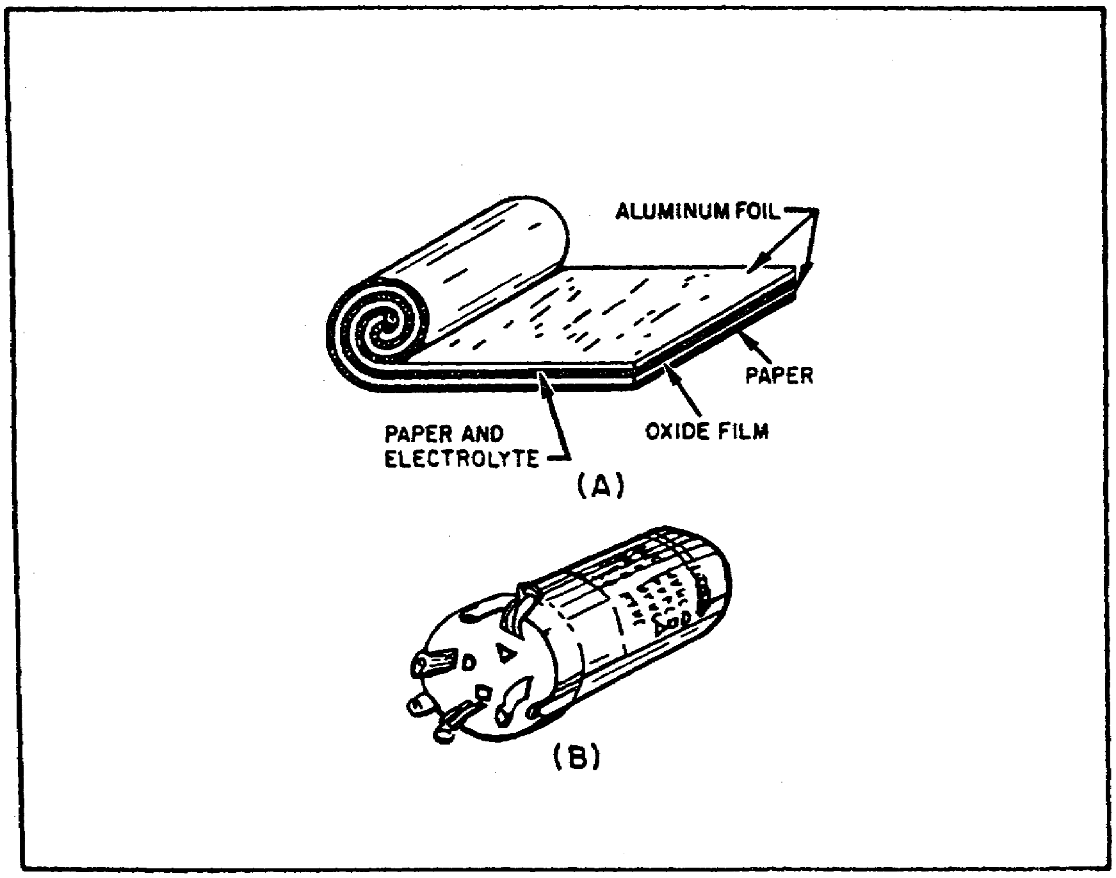


FIGURE 44. CONSTRUCTION OF AN ELECTROLYTIC CAPACITOR.

An example of a multisection electrolytic capacitor is illustrated in figure 44, view B. The four lugs at the end of the cylindrical aluminum container indicate that four electrolytic capacitors are enclosed in the can. Each section of the capacitor is electrically independent of the other sections.

It is possible for one section to be defective while the other sections are still good. The can is the common negative connection to the four capacitors. Separate terminals are provided for the positive plates of the capacitors. Each capacitor is identified by an embossed mark adjacent to the lugs, as shown in figure 44, view B, on the previous page. The identifying marks used on the electrolyte capacitor are the half moon, the triangle, the square, and no embossed mark. By looking at the bottom of the container and the identifying sheet pasted to the side of the container, it is easy to identify the value of each section.

Internally, the electrolytic capacitor is constructed similarly to the paper capacitor. The positive plate consists of aluminum foil covered with an extremely thin film of oxide. This thin film (which is formed by an electrochemical process) acts as the dielectric of the capacitor. Next to and in contact with the oxide is a strip of paper or gauze which has been impregnated with a paste-like electrolyte. The electrolyte acts as the negative plate of the capacitor. A second strip of aluminum foil is then placed against the electrolyte to provide electrical contact to the negative electrode (the electrolyte). When the three layers are in place, they are rolled into a cylinder as shown in figure 44, view A.

An electrolytic capacitor has two primary disadvantages compared to a paper capacitor in that the electrolytic type is POLARIZED and has a LOW LEAKAGE RESISTANCE. This means that should the positive plate be accidentally connected to the negative terminal of the source, the thin oxide film dielectric will dissolve and the capacitor will become ,a conductor (i.e., it will short;). The polarity of the terminals is normally marked on the case of the capacitor. Since an electrolytic capacitor is polarity sensitive, its use is ordinarily restricted to a dc circuit, or to a circuit where a small ac voltage is superimposed on a dc voltage. Special electrolytic capacitors are available for certain ac applications, such as a motor starting capacitor. Dry electrolytic capacitors vary in size from about 4 microfarads to several thousand microfarads and have a working voltage of approximately 500 volts.

The type of dielectric used and its thickness govern the amount of voltage that can safely be applied to the electrolytic capacitor. If the voltage applied to the capacitor is high enough to cause the atoms of the dielectric material to become ionized, arcing between the plates will occur. In most other types of capacitors,. arcing will destroy the capacitor. However, an electrolytic capacitor has the ability to be self-healing. If the arcing is small, the electrolytic will regenerate itself. If the arcing is too large, the capacitor will not self-heal and will become defective.

(5) *Oil Capacitors*. OIL CAPACITORS are often used in high-power electronic equipment. An oil-filled capacitor is nothing more than a paper capacitor that is immersed in oil. Since oil impregnated paper has a high dielectric constant, it can be used in the production of capacitors having a high capacitance value. Many capacitors will use oil with another dielectric material to prevent arcing between the plates of an oil-filled capacitor, because the oil will tend to reseal the hole caused by the arcing. Such a capacitor is referred to as a SELF-HEALING capacitor.

m. *Variable Capacitors*. A variable capacitor is constructed in such a manner that its value of capacitance can be varied. A typical variable capacitor (adjustable capacitor) is the rotor-stator type. It consists of two sets of metal plates arranged so that the rotor plates move between the stator plates. Air is the dielectric. As the position of the rotor is changed, the capacitance value is changed. This type of capacitor is used for tuning most radio receivers. Its physical appearance and its symbol are shown in figure 45 on the following page.

Another type of variable capacitor (trimmer capacitor) and its symbol is shown in figure 46, on the following page. This capacitor consists of two plates separated by a sheet of mica. A screw adjustment is used to vary the distance between the plates, thereby changing the capacitance.

n. *Color Codes For Capacitors*. Although the capacitance value may be printed on the body of a capacitor, it may also be indicated by a color code. The color code used to represent capacitance values is similar to that used to represent

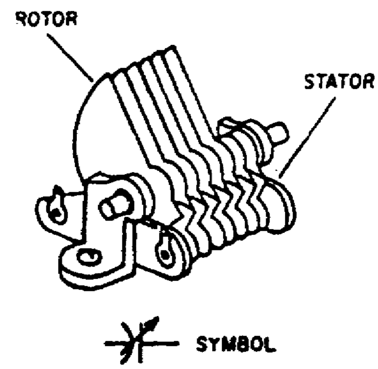


FIGURE 45. ROTOR-STATOR TYPE VARIABLE CAPACITOR.

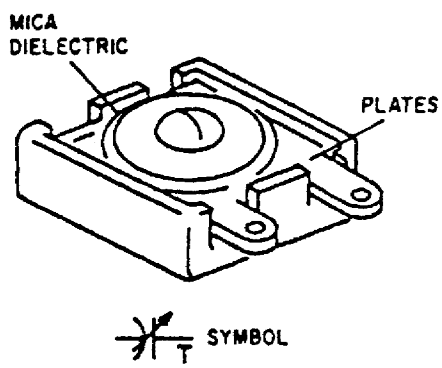


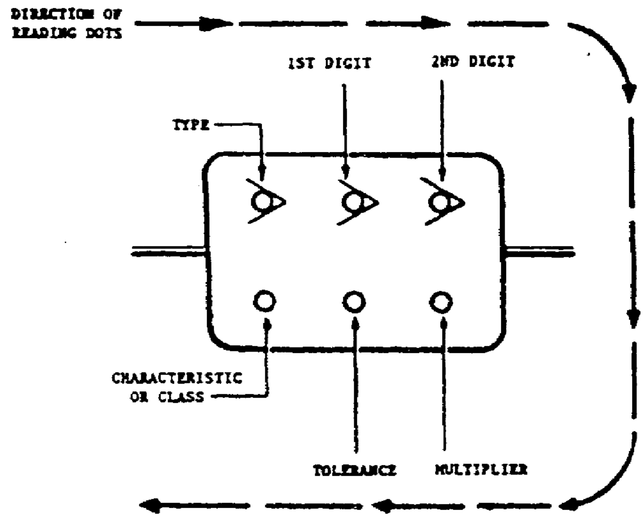
FIGURE 46. TRIMMER CAPACITOR.

resistance values. The color codes currently in popular use are the Joint Army-Navy (JAN) code and the Radio Manufacturers' Association (RMA) code.

In each of these codes, a series of colored dots or bands is used to indicate the value of the capacitor. A mica capacitor, it should be noted, may be marked with either three dots or six dots. Both the three- and the six-dot codes are similar, but the six-dot code contains more information

about the capacitor, such as working voltage and temperature coefficient.

The capacitor, shown in figure 47, represents either a mica capacitor or a molded paper capacitor. To determine the type and value of the



TYPE	COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLERANCE (PERCENT)	CHARACTERISTIC OR CLASS
JAN, MICA	BLACK	0	0	1.0	±20	APPLIES TO
	BROWN	1	1	10		TEMPERATURE
	RED	2	2	100	± 2	COEFFICIENT
	ORANGE	3	3	1,000		OR METHODS
	YELLOW	4	4	10,000		OF TESTING
	GREEN	5	5	100,000		
	BLUE	6	6	1,000,000		
	VIOLET	7	7	10,000,000		
	GRAY	8	8	100,000,000		
EIA, MICA	WHITE	9	9	1,000,000,000		
	GOLD			.1	± 5	
MOLDED PAPER	SILVER			.01	±10	
	BODY				±20	

FIGURE 47. 6-DOT COLOR CODE FOR MICA AND MOLDED PAPER CAPACITORS.

capacitor, hold the capacitor so that the three arrows point to the right (>). The first dot at the base of the arrow sequence (the left-most dot) represents the capacitor TYPE. This dot is either black, white, silver, or the same color as the capacitor body. Mica is represented by a black or white dot, and paper by a silver dot or a dot having the same color as the body of the capacitor. The two dots to the immediate right of the type dot indicate the first and second digits of the capacitance value. The dot at the bottom right represents the multiplier to be used. The multiplier represents picofarads. The dot in the bottom center indicates the tolerance value of the capacitor.

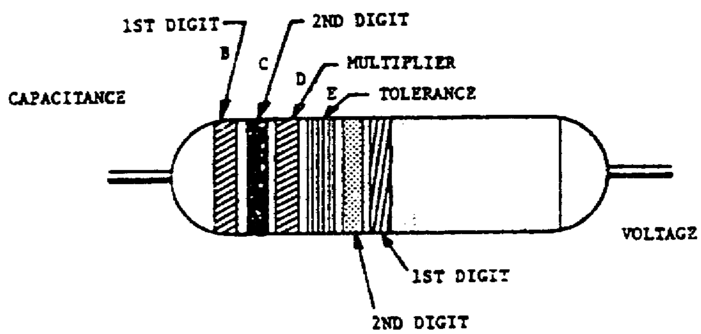
Let's assume that, we have a capacitor in our hand. To read this capacitor, first, turn the capacitor so that the arrows (>) are pointing from left to right. Read the first dot, which in this case is white. Looking at the chart in figure 47, on the previous page, we see that white indicates a mica capacitor. Now read the first digit dot (or second dot) the second dot is brown. Referring to the chart in figure 47, we see that brown indicates 1. Then read the second digit dot, which in this case is red. Looking at the chart, we see that red indicates a value of 2. This gives us, thus far, 12. Now read the multiplier dot, which is at the bottom right-hand side of the capacitor. Remember that the multiplier is in picofarads. In this case, the multiplier dot is also red. Looking at the chart., we see that red indicates a multiplier of 100. Now multiply the multiplier by the first two digits (100 x 12 = 1200 picofarads). Finally, read the last dot, which is the tolerance dot. In our (example, the tolerance dot is blue. Looking at the chart, we see that blue indicates a tolerance of + 2%.

According to the above coding, the capacitor is a mica capacitor whose capacitance is 1200 picofarads with a tolerance of ± 2%.

The capacitor shown in figure 48, on the following page, is a tubular capacitor. Because this type of capacitor always has a paper dielectric, the type of code is omitted. To read the code, hold the capacitor so that the band closest to the end is on the left side then read left to right. The last two bands (the fifth and sixth bands from the left) represent the voltage rating of the capacitor.

This means that if a capacitor is coded red, red, red, yellow, yellow, yellow, it has the following digit values.

red = 2
red = 2
red = x 100 picofarads
yellow = ± 40%
yellow = 4
yellow = 4



COLOR	CAPACITANCE 1ST DIGIT	CAPACITANCE 2ND DIGIT	CAPACITANCE MULTIPLIER	TOLERANCE (PERCENT)	VOLTAGE RATING 1ST DIGIT	VOLTAGE RATING 2ND DIGIT
BLACK	0	0	1	±20	0	0
BROWN	1	1	10		1	1
RED	2	2	100		2	2
ORANGE	3	3	1,000	±30	3	3
YELLOW	4	4	10,000	±40	4	4
GREEN	5	5	100,000	± 5	5	5
BLUE	6	6	1,000,000		6	6
VIOLET	7	7			7	7
GRAY	8	8			8	8
WHITE	9	9		±10	9	9

FIGURE 48. 6-BAND COLOR CODE FOR TUBULAR PAPER DIELECTRIC CAPACITORS.

The six digits indicate a capacitance of 2200 picofarads with a ± 40 percent tolerance and a working voltage of 44 volts.

The ceramic capacitor's color coded chart is shown in figure 49 and the mica capacitor is shown in figure 50 (on the following page). This type of mica capacitor differs from the one shown in figure 47 (on page 71) in that the arrow is solid instead of broken. This type of mica capacitor is read in the same manner as the one shown in figure 47, with one exception: the first dot indicates the first digit (Note: Because this type of capacitor is always mica, there is no need for a type dot.)

COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLERANCE: MORE THAN 10 pf (IN PERCENT)	TOLERANCE: LESS THAN 10 pf (IN pf)	TEMPERATURE COEFFICIENT*
BLACK	0	0	1.0	±20	±2.0	0
BROWN	1	1	10	± 1		-30
RED	2	2	100	± 2		-80
ORANGE	3	3	1,000			-150
YELLOW	4	4	10,000			-220
GREEN	5	5		± 5	±0.5	-330
BLUE	6	6				-470
VIOLET	7	7				-750
GRAY	8	8	.01		±0.25	+30
WHITE	9	9	.1	±10	±1.0	+120 TO -750 (EIA)
						+500 TO -330 (JAN)
SILVER						+100 (JAN)
GOLD						BYPASS OR COUPLING (EIA)

*PARTS PER MILLION PER DEGREE CENTIGRADE.

FIGURE 49. CERAMIC CAPACITOR COLOR CODE.

COLOR	1 ST DIGIT	2ND DIGIT	MULTIPLIER	TOLERANCE (PERCENT)	VOLTAGE RATING
BLACK	0	0	1.0		
BROWN	1	1	10	± 1	100
RED	2	2	100	± 2	200
ORANGE	3	3	1,000	± 3	300
YELLOW	4	4	10,000	± 4	400
GREEN	5	5	100,000	± 5	500
BLUE	6	6	1,000,000	± 6	600
VIOLET	7	7	10,000,000	± 7	700
GRAY	8	8	100,000,000	± 8	800
WHITE	9	9	1,000,000,000	± 9	900
GOLD			.1		1000
SILVER			.01	±10	2000
BODY				±20	*

* WHERE NO COLOR IS INDICATED, THE VOLTAGE RATING MAY BE AS LOW AS 300 VOLTS.

FIGURE 50. MICA CAPACITOR COLOR CODE.

5. Alternating Current Production

a. *Alternating Current (AC) and Direct Current (DC).* Alternating current is current which constantly changes in amplitude, and which reverses direction at regular intervals. Previously, we learned that direct current flows only in one direction, and that the amplitude of current is determined by the number of electrons flowing past a point in a circuit in one second. If, for example, a coulomb of electrons moves past a point in a wire in one second, and all the electrons are moving in the same direction, the amplitude of direct current in the wire is one ampere. Similarly, if half a coulomb of electrons moves in one direction past a point in the wire in half a second, then reverses direction, moving past the same point in the opposite direction during the next half-second, a total of one coulomb of electron passes the point in one second. The amplitude of the alternating current is one ampere. The preceding comparison of dc and ac is illustrated in figure 51. Notice that one white arrow plus one striped arrow comprise one coulomb.

1. *Disadvantages of DC (Compared to AC*. When commercial use of electricity became wide-spread in the United States, certain disadvantages in using direct current in the home became apparent. If a commercial direct current system is used, the voltage must be generated at the level (amplitude or value) required by the load. To properly light a 240 volt lamp, for example, the dc generator must deliver 240 volts. If a 120 volt lamp is to be supplied power from the 240 volt generator, a resistor or another 120 volt lamp must be placed in series with the 120 volt lamp to drop the extra 120 volts. When the resistor is used to reduce the voltage, an amount of power equal to that consumed by the lamp is wasted.

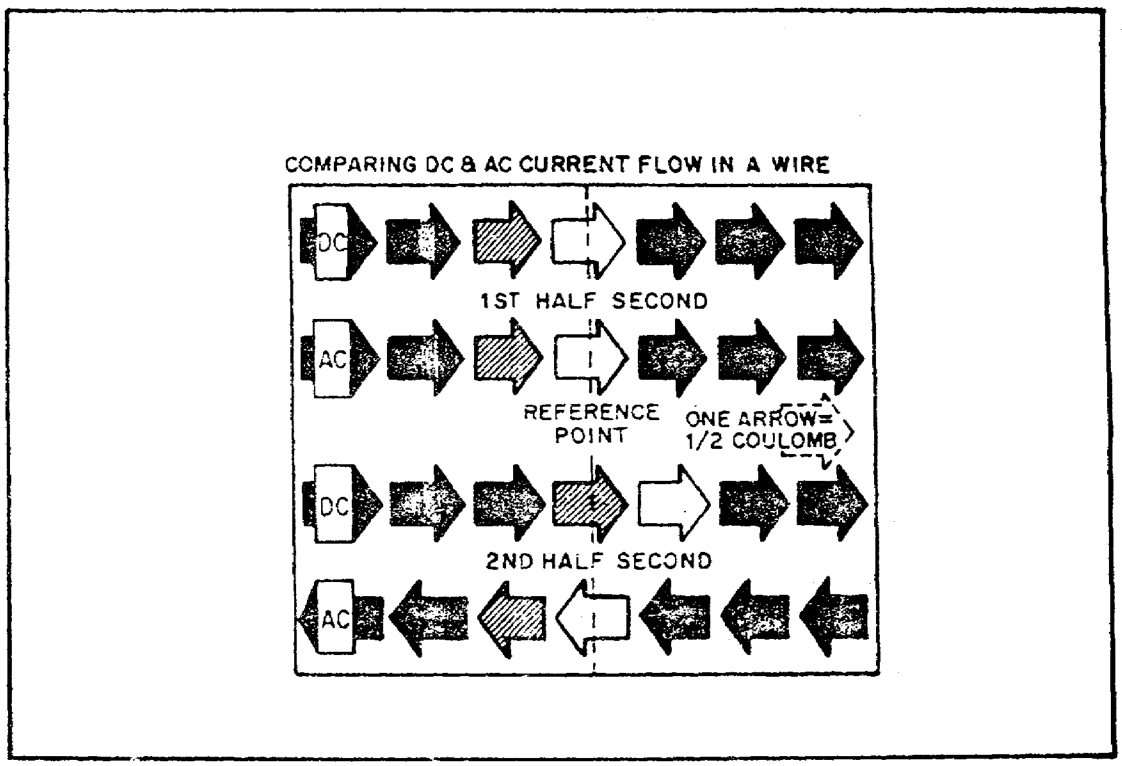


FIGURE 51. COMPARING DC & AC CURRENT FLOW IN A WIRE.

Another disadvantage of the direct current system becomes evident when the direct current (I) from the generating station must be transmitted a long distance over wire to The consumer. When this happens, a large amount of power is lost due to the resistance (R) of the wire. The power loss is equal to I^2R. However, this loss can be greatly reduced if the power is transmitted over the lines at a very high voltage level and a low current level. This is not a practical solution to the power loss in the dc system since the load would then have to be operated at dangerously high voltage. Because. of the disadvantages related to transmitting and using direct current, practically all modern commercial electric power companies generate and distribute alternating current (ac).

Unlike direct voltages, alternating voltages can be stepped up or down in amplitude by a device called a TRANSFORMER. Use of the transformer permits efficient transmission of electrical power over long-distance lines. At the electrical power station, the transformer output power is at high voltage and low current levels. At the consumer end of the transmission lines, the voltage is stepped down by a transformer to the value required by the load. Due to its inherent advantages and versatility, alternating current has replaced direct current in all but a few commercial power distribution systems.

c. *Voltage Waveforms*. We now know that there are two types of current and voltage, that is, direct current and voltage and alternating current and voltage. If a graph is constructed showing the amplitude of a dc voltage across the terminals of a battery with respect to time, it will appear as in figure 52, view A, on the following page. The dc voltage is shown to have a constant amplitude. Some voltages go through periodic changes in amplitude like those shown in figure 52, view B. The pattern which results when these changes in amplitude with respect to time are plotted on graph paper is known as a WAVEFORM. Figure 52, view B, shows some of the common electrical waveforms. Of those illustrated, the sine wave will be dealt with most often.

d. *Electromagnetism*. The sine wave illustrated in figure 52, view B, is a plot of a current which changes amplitude and direction. Although there are several ways of producing this current, the method based on the principles of electromagnetic induct ion is by far the easiest and most common method in use.

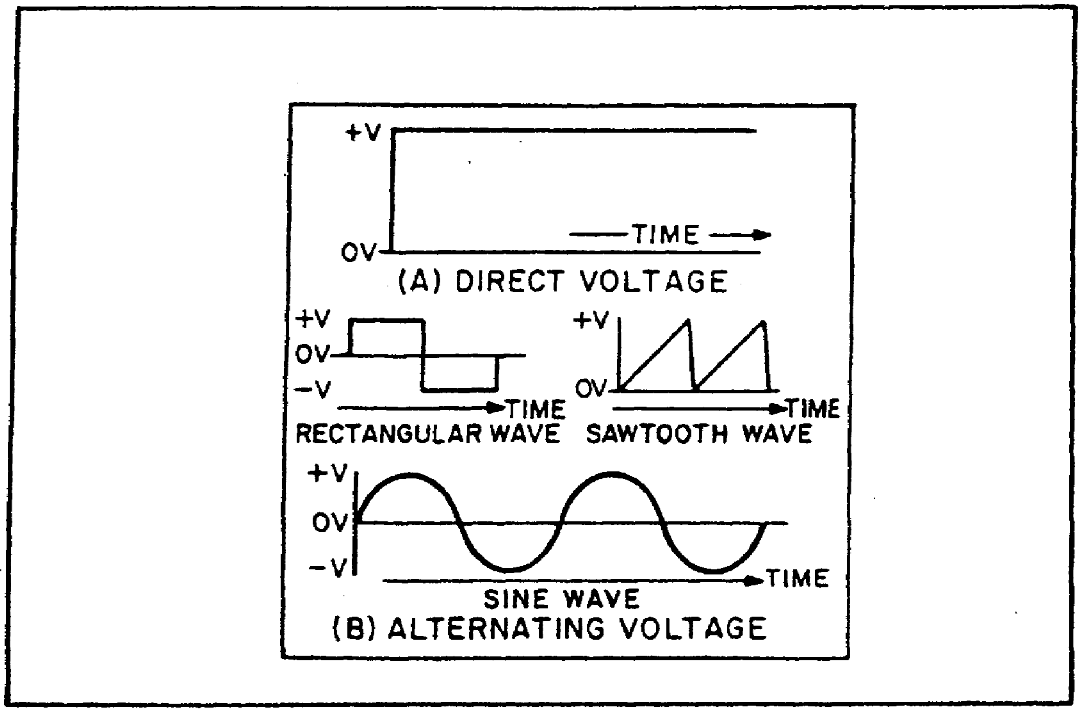


FIGURE 52. VOLTAGE WAVEFORMS.

The fundamental theories concerning simple magnets and magnetism were covered earlier in this task (pages 2 through 40), but how magnetism can be used to produce electricity was only briefly mentioned. The following paragraphs will give a more in-depth study of magnetism. The main points that will be explained are how magnetism is affected by an electric current and, conversely, how electricity is affected by magnetism. This general subject area is most often referred to as ELECTROMAGNETISM. To become proficient in the electrical field, the student must first become familiar with the relationship between magnetism and electricity. For example, he must know that:

(1) An electric current always produces some form of magnetism.

(2) The most commonly used means for producing or using electricity involves magnetism.

(3) The peculiar behavior of electricity under certain conditions is caused by magnetic influences.

e. *Magnetic Fields*. In 1819, Hans Christian Oersted, a Danish physicist, found that a definite

relationship exists between magnetism and electricity. He discovered that an electric current is always accompanied by certain magnetic effects and that these effects obey definite laws.

If a compass is placed in the vicinity of a current-carrying conduct or, the compass needle will align itself at right angles to the conductor, thus indicating the presence of a magnetic force. One can demonstrate the presence of this force by using the arrangement illustrated in figure 53. In both view A and view B of figure 53, current flows in a vertical conductor through a horizontal piece of cardboard. One can determine the direction of

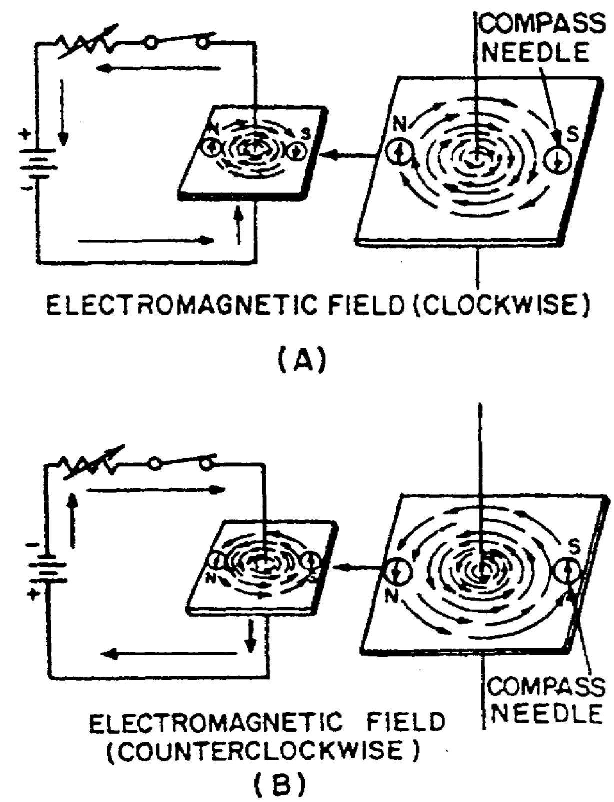


FIGURE 53. MAGNETIC FIELD AROUND A CURRENT-CARRYING CONDUCTOR.

this electromagnetic force produced by the current by placing a compass at various points on the cardboard and noting the compass needle deflection. The direction of the magnetic force is assumed to be the direction in which the north pole of the compass points.

In figure 53, view A, on the previous page, the needle deflections show that a magnetic field exists in the circular form around the conductor. When the current flows upward (figure 53, view A), the direction of the field is clockwise, as viewed from the top. However, if you reverse the polarity of the battery so that the current flows downward (figure 53, view B), the direction of the field is counterclockwise.

The relation between the direction of the magnetic lines of force around a conductor and the direction of current in the conductor may be determined by means of the LEFT-HAND RULE FOR A CONDUCTOR: if you grasp the conductor in your left hand with the thumb extended in the direction of the electron flow (current (- to +), your fingers point in the direction of the magnetic lines of force. Now apply this rule to figure 54 (on the following page). Note that your fingers point in the direction of the north pole of the compass points when it is placed in the magnetic field surrounding the wire.

An arrow is generally used(in electrical diagrams to denote the direction of current in a length of wire (figure 54, view A). Where across section of a wire is shown, an end view of the arrow is used. A cross-sectional view of a conductor that is carrying current toward the observer is illustrated in figure 5,1, view B. Note that the direction of current is indicated by a (dot, representing the head of the arrow. A conductor that is carrying current away from the observer is illustrated in figure 54, view C. Note that the direction of current is indicated by a cross, representing the tail of the arrow. Also note that the magnetic field around a current-carrying conductor is perpendicular to the conductor, and that the magnetic lines of force are equal along all parts of the conductor.

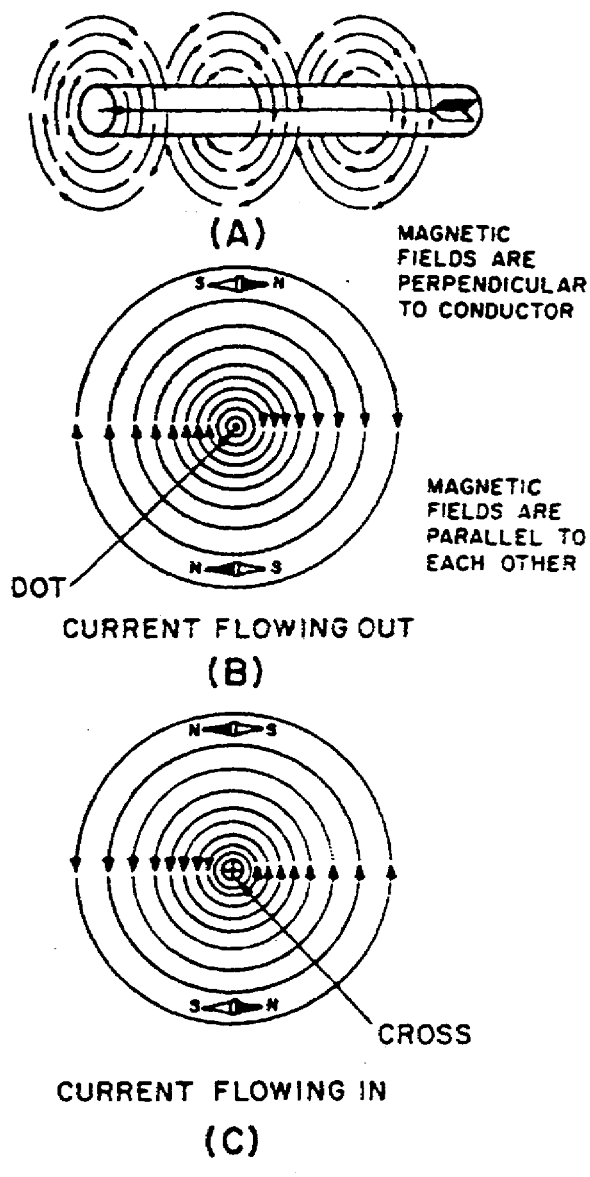


FIGURE 54. THE MAGNETIC FIELD AROUND A CURRENT-CARRYING CONDUCTOR, DETAILED VIEW.

When two adjacent parallel conductors are carrying current in the same direction, the magnetic lines of force combine and increase the strength of the field around the conductors, as shown in figure 55, view A, on the following page. Two parallel conductors carrying currents in opposite directions are shown in figure 55, view B. Note that the field around one conductor is opposite in direction to the field around the other conductor. The resulting lines of force oppose each other in the space between the wires, thus deforming the field around each conductor. This means that if two parallel and adjacent conductors are carrying currents in the same direction, the fields about the two conductors aid each other. Conversely, if the two conductors are carrying currents in opposite directions, the fields about the conductors repel each other.

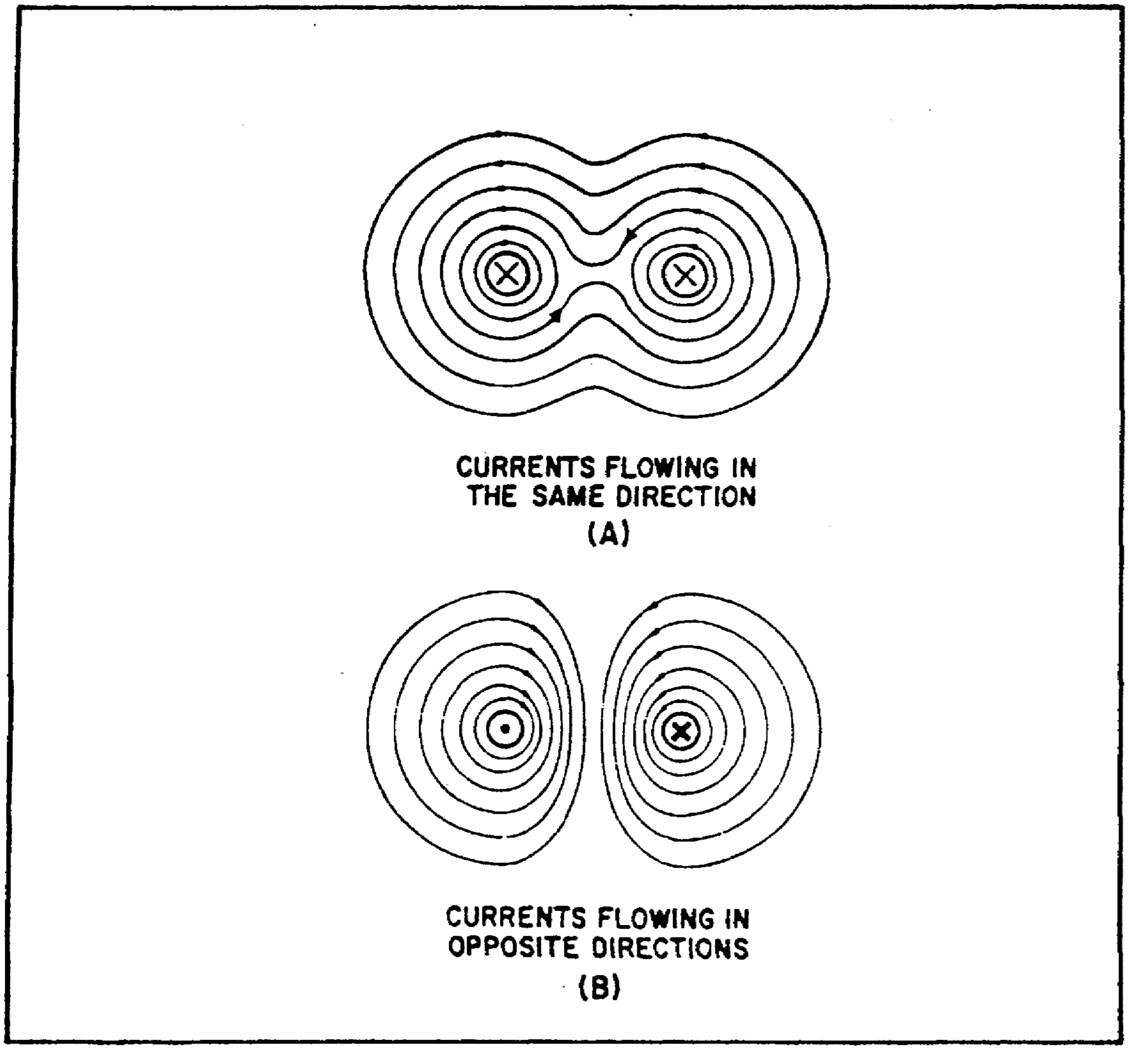


FIGURE 55. MAGNETIC FIELD AROUND TWO PARALLEL CONDUCTORS.

f. *Magnetic Field of a Coil*. Figure 54 (on the previous page) illustrates that the magnetic field around a current-carrying wire exists at all points along the wire. Figure 56 illustrates that when a straight wire is wound around a core, it forms a coil and that the magnetic field about the core assumes a different shape. Figure 56, view A, is actually a partial cutaway view showing the construction of a simple coil. Figure 56, view B, shows a cross-sectional view of the same coil. Notice that the two ends of the coil are identified x and y.

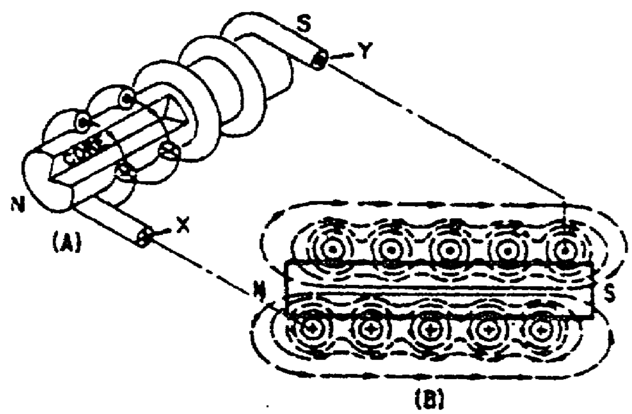


FIGURE 56. MAGNETIC FIELD PRODUCED BY A CURRENT-CARRYING COIL.

When current is passed through the coil, the magnetic field about each turn of the wire links with the fields of the adjacent turns (figure 56, view A). The combined influence of all the turns produces a two-pole field similar to that of a simple bar magnet. One end of this coil is a north pole and the other end is a south pole.

(1) *Polarity of an Electromagnetic Coil.* In figure 53 on page 79, we observed that the direction of the magnetic field around a straight wire depends on the direction of current in that wire. Thus, a reversal of current in a wire causes a reversal in the direction of the magnetic field that. is produced. It follows that a reversal of the current in a coil also causes a reversal of the two-pole magnetic field about the coil.

When the direction of the current in a coil is known, one can determine the magnetic polarity of the coil by using the LEFT-HAND RULE FOR COILS.

This rule is illustrated in figure 57, and is stated as follows: Grasp the coil in your left hand, with your fingers "wrapped around" in the direction of the current. You thumb will point toward the north pole of the coil.

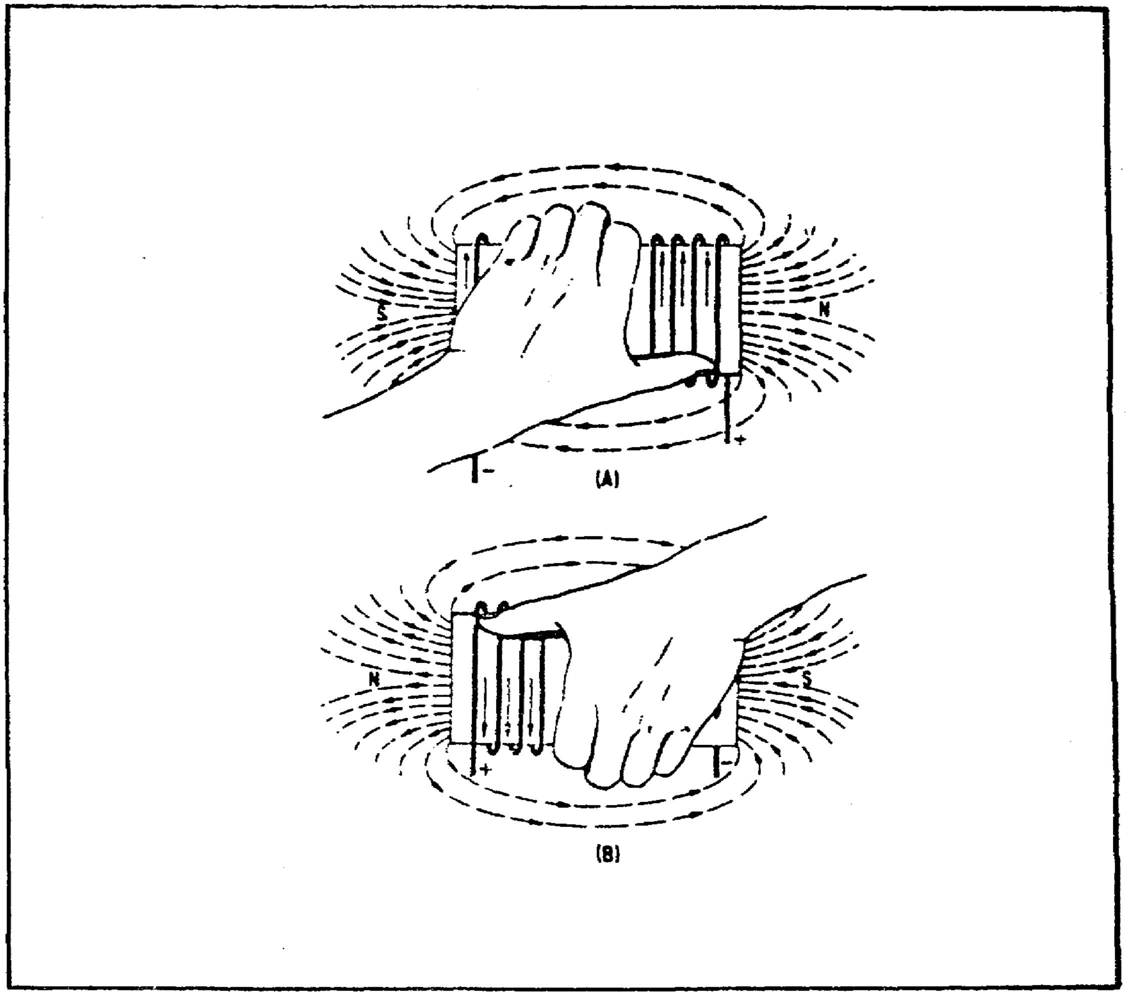


FIGURE 57. LEFT-HAND RULE FOR COILS.

(2) *Strength of an Electromagnetic Field*. The strength or intensity of a coil's magnetic field depends on a number of factors. The main ones are listed below and will be discussed again later.

(a) The number of turns of wire in the coil.

(b) The amount of current flowing in the coil.

(c) The ratio of the coil length to the coil width.

(d) The type of material in the core.

(3) *Losses in an Electromagnetic Field*. When current flows in a conductor, the atoms in the conductor all line up in a definite direction, producing a magnetic field. When the direction of the current changes, the direction of the atoms' alignment also changes, causing the magnetic field to change direction. To reverse all the atoms requires that power be expended, and this power is lost. This loss of power (in the form of heat) is called HYSTERESIS LOSS. Hysteresis loss is common to all ac equipment; however, it causes few problems except in motors, generators, and transformers.

g. *Basic AC Generation*. From the previous discussion, it was learned that a current-carrying conductor produces a magnetic field around itself, and that a changing magnetic field produces an emf in a conductor. That is, if a conductor is placed in a magnetic field, and either the field or the conductor moves, an emf is induced in the conductor. This effect is called electromagnetic induction.

(1) *Cycle*. Figures 58 and 59 on the following two pages show a suspended loop of wire (conductor) being rotated (moved) in a clockwise direction through the magnetic field between the poles of a permanent magnet. For ease of explanation, the loop has been divided into a dark half and a light half. Notice in view A of the figures that the dark half is moving along (parallel to) the lines of force. Consequently, it is cutting NO lines of force. The same is true of the light half, which is moving in the opposite direction. Since the conductors are cutting no lines of force, no emf is induced. As the loop rotates toward the position shown in figure 59, view B, on the previous page, it. cuts more and more lines of force per second (inducing ail ever increasing voltage) because : it is more directly across the field (lines of force). At figure 59, view B, the conductor is shown completing one-quarter of a complete revolution, or 90°, of a complete circle. Because the conductor is now

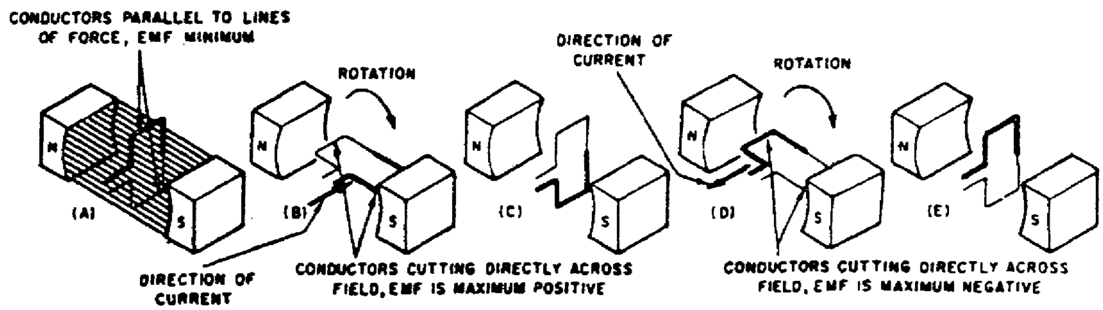


FIGURE 58. SIMPLE ALTERNATING-CURRENT GENERATOR.

cutting directly across the field, the voltage induced in the conductor is maximum. If the rotation from figure 59, view A and view B, on the following page, is plotted on a graph (and the points connected), a curve will start to appear.

As the loop continues to be rotated toward the position shown in figure 59, view C, it cuts fewer and fewer lines of force. The induced voltage decreases from its peak value. Eventually, the loop is moving in a plane parallel to the magnetic field, and no emf is induced in the conductor.

The loop has now been rotated through half a circle (one alternation or 180°). If the preceding quarter-cycle is plotted, it appears as shown in figure 59 (one alternation or 0-180°).

When the same procedure is applied to the second half of rotation (180° through 360°), the curve appears as shown in figure 59. Notice that the only difference is the polarity of the induced voltage. Where previously the polarity was positive, it is now negative. The sine curve shows the induced voltage at each instant of time during rotation of the loop. Notice that this curve contains 360°, or two alternations. TWO ALTERNATIONS represent ONE complete CYCLE of rotation.

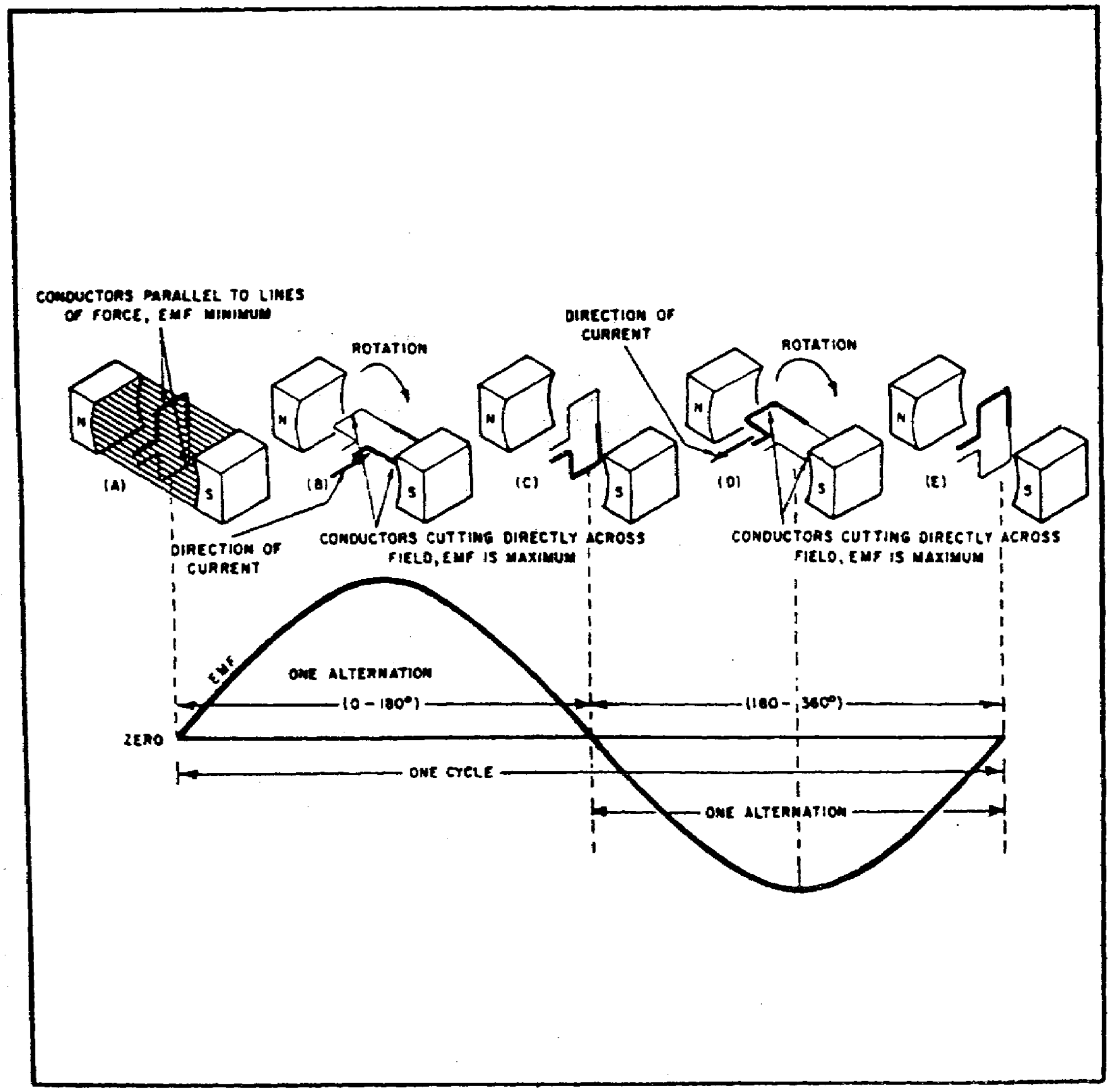


FIGURE 59. BASIC ALTERNATING-CURRENT GENERATOR.

Assuming a closed path is provided across the ends of the conductor loop, you can determine the direction of current in the loop by using the LEFT-HAND RULE FOR GENERATORS. Refer to figure 60 on the following page. The left-hand rule is applied as follows: First, place your left hand on the illustration with the fingers as shown. Your THUMB will point in the direction of rotation (relative movement of the wire to the magnetic field); your FOREFINGER will point in the direction of magnetic flux (north to south); and your MIDDLE FINGER (pointing out of the paper) will point in the direction of current flow.

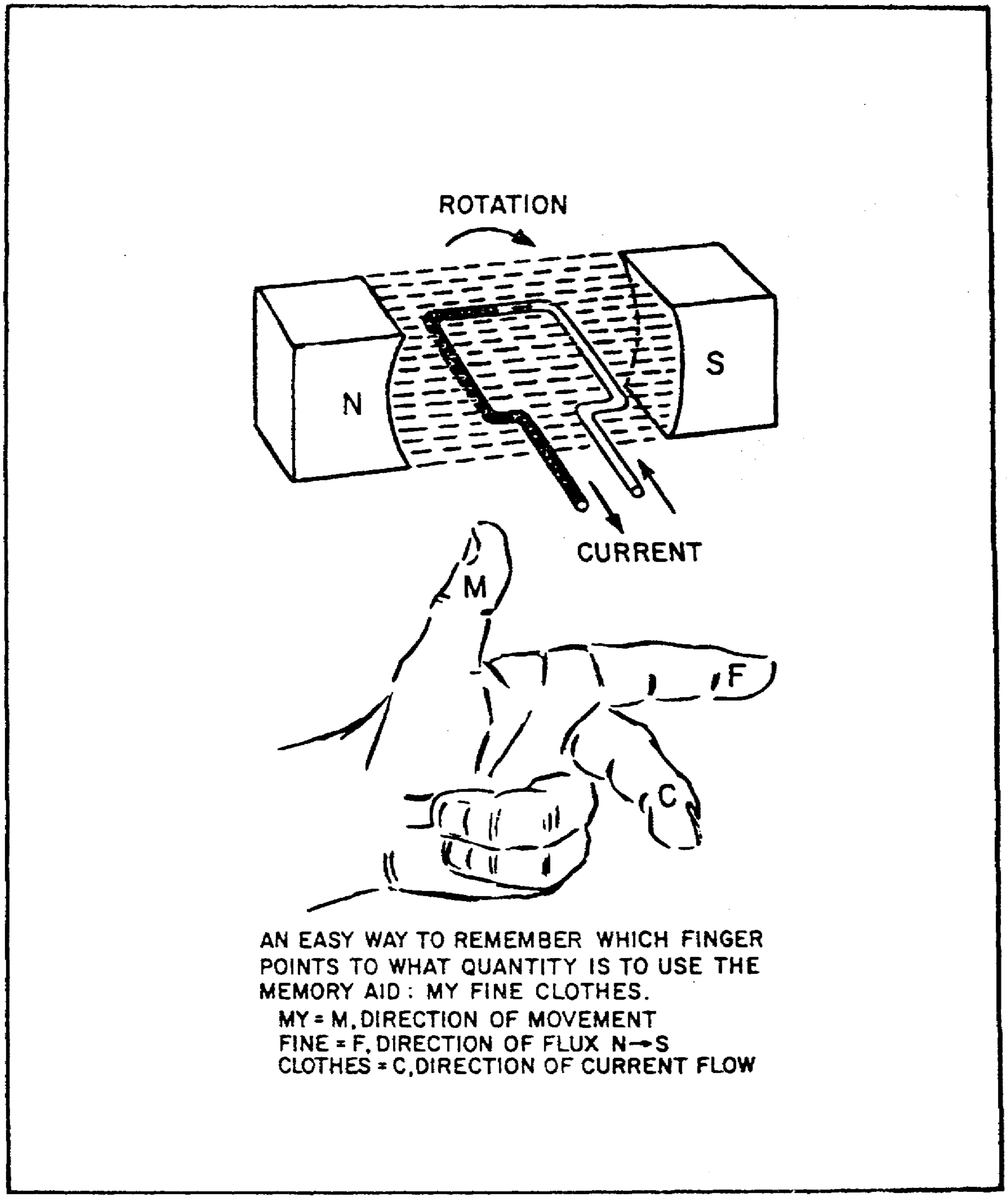


FIGURE 60. LEFT-HAND RULE FOR GENERATORS.

By applying the left-hand rule to the dark half of the loop in view B, figure 59, on page 87, one will find that the current flows in the direction indicated by the heavy arrow. Similarly, by using the left-hand rule on the light half of the loop, one will find that current therein flows in the opposite direction. The two induced voltages in the loop add together to form one total emf.. It is this emf which causes the current in the loop.

When the loop rotates to the position shown in view D, figure 59, the action reverses. The dark half is moving up instead of down, and the light half is moving down instead of up. By applying the left-hand rule once again, you will see that the total induced emf and its resulting current have reversed direction. The voltage builds up to maximum in this new direction, as shown by the curve in figure 59. The loop finally returns to its original position, figure 59, view E, at which point voltage is again at zero. The sine curve represents one complete cycle of voltage generated by the rotating loop. All the illustrations used in this topic show the wire loop moving in a clockwise direction. In actual practice, the loop can be moved clockwise or counterclockwise. Regardless of the direction of movement, the left-hand rule applies.

If the loop is rotated through 360° at a steady rate, and if the strength of the magnetic field is uniform, the voltage produced is a sine wave of voltage, as indicated in figure 59. Continuous rotation of the loop will produce a series of sine-wave voltage cycles or, in other words, an ac voltage.

As mentioned previously, the cycle consists of two complete alternations in a period of time. Recently, the HERTZ (Hz) has been designated to indicate one cycle per second. If ONE CYCLE PER SECOND is ONE HERTZ, then 100 cycles per second are equal to 100 Hertz, and so on. Throughout this subcourse, the term cycle is used when no specific time element is involved, and the term Hertz (Hz) is used when the time element is measured in seconds.

(2) *Frequency*. If the loop in figure 59 makes one complete revolution each second (1 Hz), increasing the number of revolutions to two per second will produce two complete cycles of ac per second (2 Hz). The number of complete cycles of

alternating current or voltage completed each second is referred to as the FREQUENCY. Frequency is always measured and expressed in Hertz.

Alternating-current frequency is an important term to understand since most ac electrical equipment requires a specific frequency for proper operation.

(3) *Period*. An individual cycle of any sine wave represents a definite amount of time. Notice that figure 61 shows 2 cycles of a sine wave which has a frequency of 2 Hertz (Hz). Since 2 cycles occur each second, 1 cycle must require one-half second of time. The time required to complete one cycle of a waveform is called the PERIOD of the wave. In the example in figure 61, the period is one-half second. The relationship between time (t) and frequency (f) is indicated by the formulas

$$t = \frac{1}{f} \text{ and } f = \frac{1}{t}$$

where t = period of time in seconds and
f = frequency in Hertz

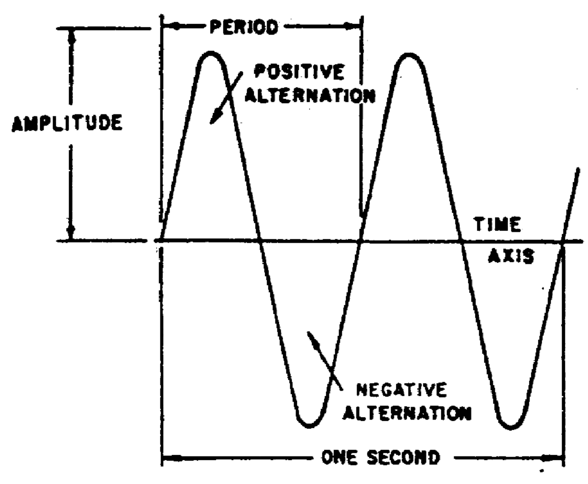


FIGURE 61. PERIOD OF SINE WAVE.

Each cycle of the sine wave shown in figure 61, on the previous page, consists of two identically shaped variations in voltage. The variation which occurs during the time the voltage is positive is called the POSITIVE ALTERNATION. The variation which occurs during the time the voltage is negative is called the NEGATIVE ALTERNATION. In a sine wave, these two alternations are identical in size and shape, but opposite polarity.

The distance from zero to the maximum value of each alternation is called the AMPLITUDE. The amplitude of the positive alternation and the amplitude of the negative alternation are the same.

h. *Wavelength*. The time it takes for a sine wave to complete one cycle is defined as the period of the waveform. The distance traveled by the sine wave during this period is referred to as WAVELENGTH. The wavelength is the distance along the waveform from one point to the same point on the next cycle. You can observe this relationship by examining figure 62. The point on the waveform where measurement of the wavelength begins is not important as long as the distance is measured to the same point on the next cycle (figure 63 on the following page).

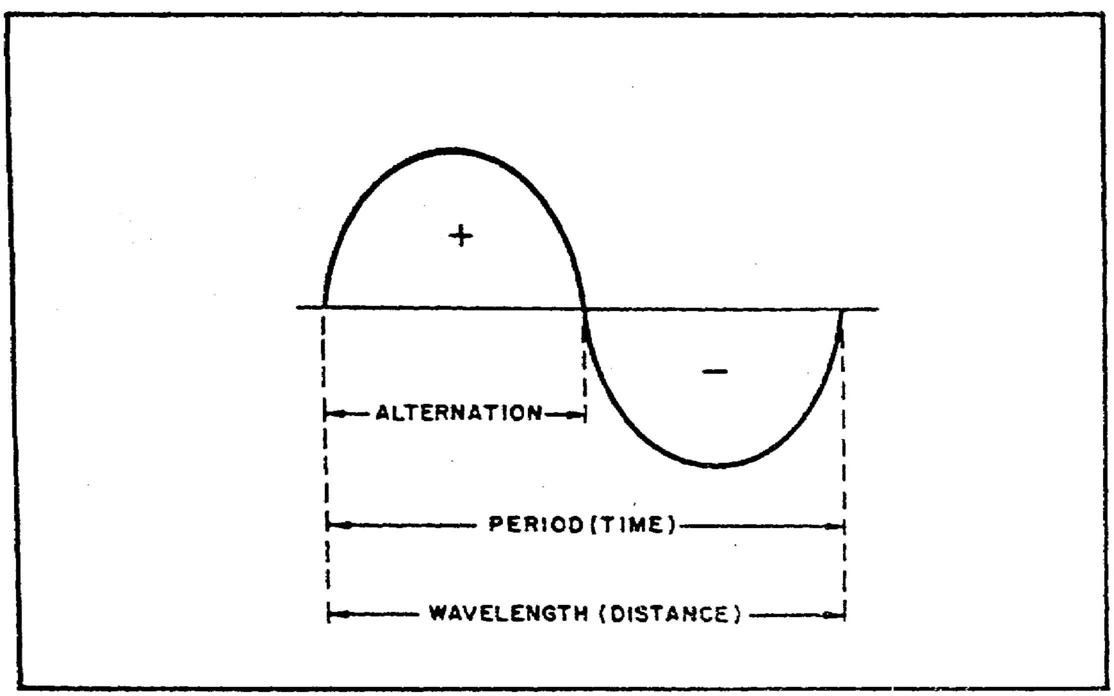


FIGURE 62. WAVELENGTH.

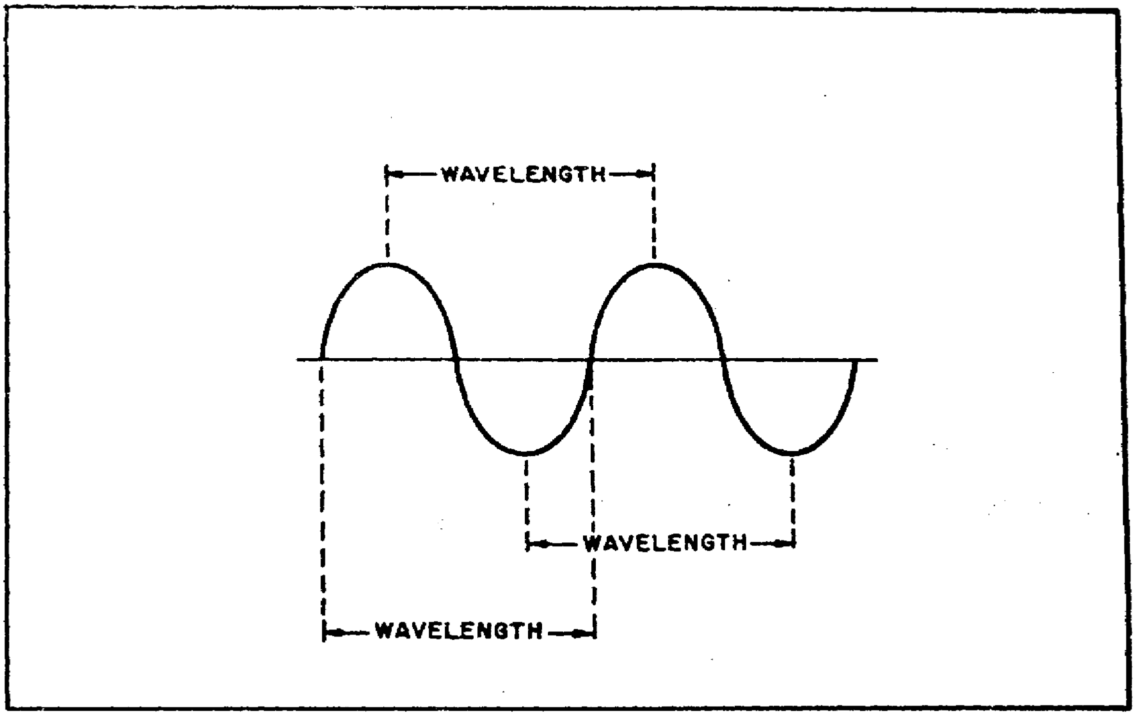


FIGURE 63. WAVELENGTH MEASUREMENT.

i. *Alternating Current Values*. In discussing alternating current and voltage, it is often necessary to express the current and voltage in terms of MAXIMUM or PEAK values, PEAK-to-PEAK values, EFFECTIVE values, AVERAGE values, or INSTANTANEOUS values. Each of these values has a different meaning and is used to describe a different amount of current or voltage.

(1) *PEAK And PEAK-TO-PEAK Values*. Refer to figure 64 on the following page. Notice it shows the positive alternation of a sine wave (a half-cycle of ac) and a dc waveform that occur simultaneously. Note that the do starts and stops at the same moment as does the positive alternation, and that both waveforms rise to the same maximum value. However, the dc values are greater than the corresponding ac values at all points except the point at which the positive alternation passes through its maximum value. <u>At this point the dc and ac values are equal. This point on the sine wave is referred to as the maximum or peak value.</u>

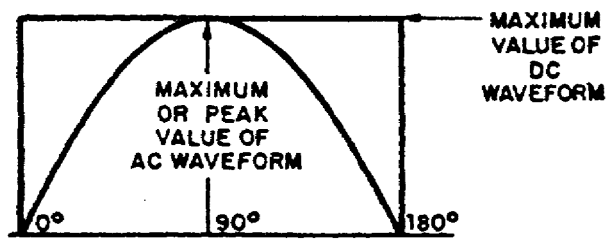


FIGURE 64. MAXIMUM OR PEAK VALUE.

During each complete cycle of ac there are always two maximum or peak values, one for the positive half-cycle and the other for the negative half-cycle. The difference between the peak positive value and the peak negative value is called the peak-to-peak value of the sine wave. This value is twice the maximum or peak value of the sine wave and is sometimes used for measurement of ac voltages. Note the difference between peak and peak-to-peak values in figure 65 on the following page. Usually alternating voltage and current are expressed in EFFECTIVE VALUES rather than in peak-to-peak values.

(2) *Instantaneous Value*. The INSTANTANEOUS value of an alternating voltage or current is the value of voltage or current at one particular instant. The value may be zero if the particular instant is the time cycle at. which the polarity of the voltage is changing. It may also be the same as the peak value, if the selected instant, is the time in the cycle at which the voltage or current stops increasing and starts decreasing. There are actually an infinite number of instantaneous values between zero and the peak value.

(3) *Average Value*. The AVERAGE value of an alternating current or voltage is the average of ALL the INSTANTANEOUS values during ONE alternation. Since the voltage increases from zero to peak value and decreases back to zero during one alternation, the average value must be some value

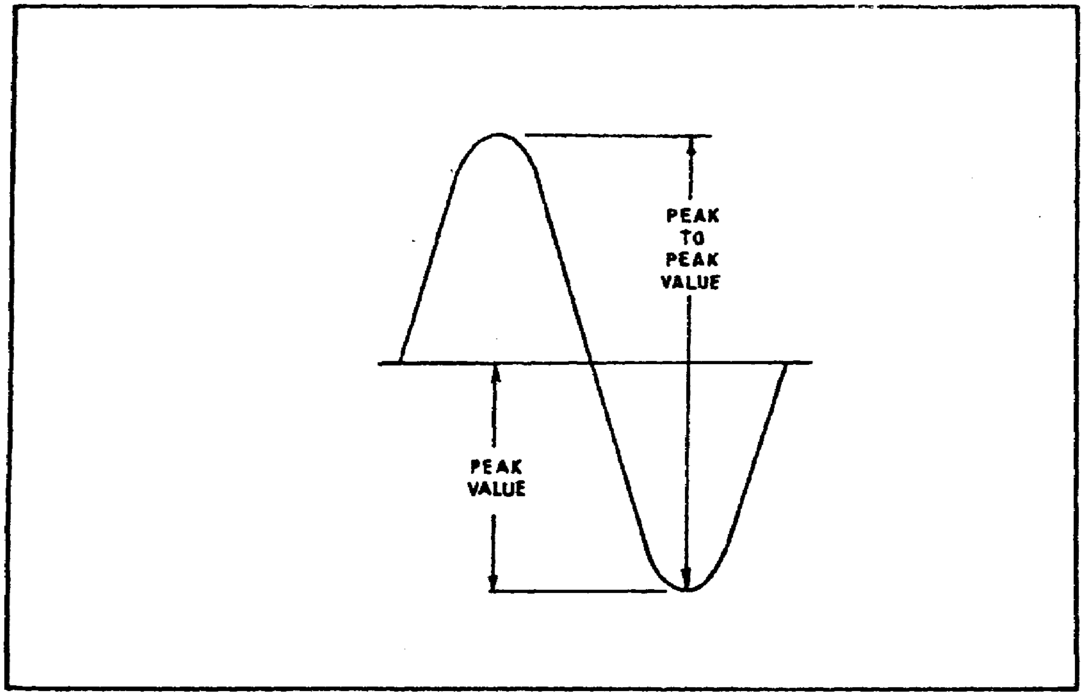


FIGURE 65. PEAK AND PEAK-TO-PEAK VALUES.

between those two limits. You could determine the average value by adding together a series of instantaneous values of the alternation (between 0° and 180°), and then dividing the sum by the number of instantaneous values used. The computation would show that one alternation of a sine wave has an average value equal to 0.636 times the peak value. The formula for average voltage is:

$$E_{avg} = 0.636 \times E_{max}$$

where E_{avg} is the average voltage of one alternation, and E_{max} is the maximum or peak voltage. Similarly, the formula for average current is:

$$I_{avg} = 0.636 \times I_{max}$$

where I_{avg} is the average current of one alternation, and I_{max} is the maximum or peak current.

Do not confuse the above definition of an average, value with that of the average value of a complete cycle. Because the voltage is positive during one alternation and negative during the other alternation, the average value of the voltage values occurring during the complete cycle is zero.

j. *Effective Value of a Sine Wave*. E_{max} E_{avg}, I_{max} and I_{avg} are values used in ac measurements. Another value used is the EFFECTIVE value of ac. This is the value of alternating voltage or current that will have the same effect on a resistance as a comparable value of direct voltage or current will have on the same resistance.

In an earlier discussion, it was stated that when current flows in a resistance, heat is produced. When direct current flows in a resistance, the amount of electrical power converted into heat equals I^2R Watts. However, because an alternating current having a maximum value of 1 ampere does not maintain a constant value, the alternating current will not produce as much heat in the resistance as will a direct current of 1 ampere.

Figure 66 compares the heating effect of 1 ampere of dc to the heating effect, of 1 ampere of ac.

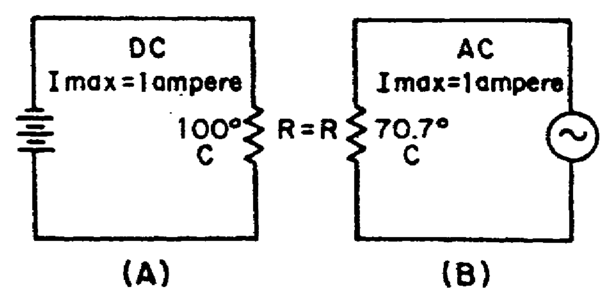


FIGURE 66. HEATING EFFECT OF AC AND DC.

Examine figure 66; views A and B, and notice that the heat (70.7° C) produced by 1 ampere of alternating current (that is, an ac with a maximum value of 1 ampere) is only 70.7 percent of the heat (100° C) produced by 1 ampere of direct current.

Mathematically,

$$\frac{\text{The heating effect of I maximum ac ampere}}{\text{The heating effect of 1 maximum dc ampere}} = \frac{70.7° \text{ C}}{100° \text{ C}} = 0.707$$

Therefore, the effective value of ac (I_{eff}) = 0.707 x I_{max}.

The rate at which heat is produced in a resistance forms a convenient basis for establishing an effective value of alternating current, and is known as the "heating effect" method. An alternating current is said to have an effective value of one ampere when it produces heat in a given resistance at the same rate as does one ampere of direct current.

You can compute the effective value of a sine wave of current to a fair degree of accuracy by taking equally spaced instantaneous values of current along the curve and extracting the square root of the average of the sum of the squared values.

For this reason, the effective value is often cat led the "root mean square" (rms) value. Thus, I_{eff} = average of the sum of the squares of I_{inst}. Stated another way, the effective or rms value (I_{eff}) of a sine wave of current is 0.707 times the maximum value of current (I_{max}). Thus, I_{eff} = 1.414 x I_{eff}.

To identify the source of the constant 1.414, examine figure 66 on the previous page. Assume that the dc in figure 66, view A, is maintained at 1 ampere and the resistor temperature is 100° C. Also assume that the ac in figure 66, view B, is increased until the temperature of the resistor is 100° C. At this point, it is found that a maximum ac value of 1.414 amperes is required in order to have the same heating effect as a 1 ampere direct current. Therefore, in the ac circuit the maximum current required is 1.414 times the effective current. It is important to remember that relationship, and that the effective value (I_{eff}) of any sine wave of current is always 0.707 times the maximum value (I_{max}).

Because alternating current is caused by an alternating voltage, the ratio of the effective

value of the voltage to the maximum value of voltage is the same as the ratio of the effective value of current to the maximum value of current. Stated another way, the effective or rms value (E_{eff}) of a sine-wave of voltage is 0.707 times the maximum value of voltage (E_{max}).

Thus,

R_{eff} -- $\sqrt{\text{Average of the sum of the squares of } E_{inst}}$

or, $E_{eff} = \sqrt{0.707 \text{ x } E_{max}}$

and, $E_{max} = \sqrt{1.414 \text{ x } E_{eff}}$

When an alternating current or voltage value is specified in a book or on a diagram, the value is an effective value unless there is a definite statement to the contrary. Remember that all meters, unless marked to the contrary, are calibrated to indicate effective values of current and voltage.

Figure 67 shows the relationship between the various values used to indicate sine-wave amplitude. Review the values in the figure to ensure that you understand what each value indicates.

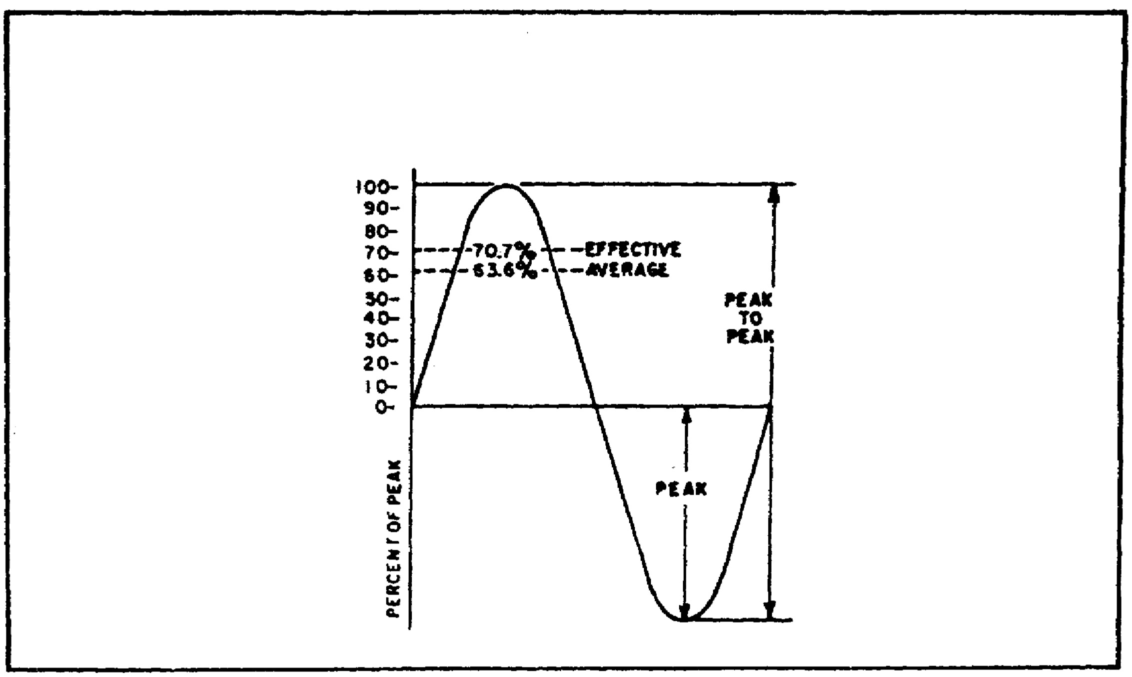


FIGURE 67. VARIOUS VALUES USED TO INDICATE SINE-WAVE AMPLITUDE.

k. *Sine Waves in Phase*. When a sine wave is applied to a resistance, the resulting current is also a sine wave. This follows Ohm's law which states that current is directly proportional to the applied voltage. Now examine figure 68. Notice that the sine wave of voltage and the resulting sine wave of (current are superimposed on the same time axis. Notice also that as the voltage increases in a positive direction, the current increases along with it, and that when the voltage reverses direction, the current also reverses direction. When two sine waves, such as those represented in figure 68, are precisely in step with one another, they are said to be IN PHASE. To be in phase, the two sine waves must go through their maximum and minimum points at the same time and in the same direction.

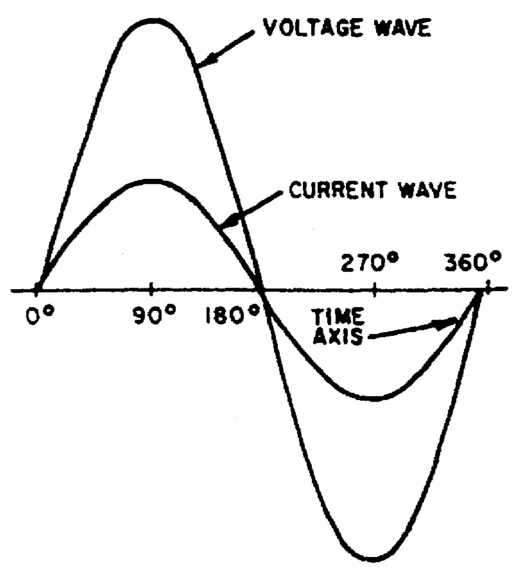


FIGURE 68. VOLTAGE AND CURRENT WAVES IN PHASE.

In some circuits, several sine waves can be in phase with each other. Thus, it is possible to have two or more voltage drops in phase with each other and also be in phase with the circuit current.

1. *Sine Waves Out of Phase*. Figure 69 shows voltage wave E_1 which is considered to start at 0° (time one). As voltage wave E_1 reaches its positive peak, voltage wave E_2 starts its rise (time two). Since these voltage waves do not go through their maximum and minimum points at the same instant of time, a PHASE DIFFERENCE exists between the two waves. The two waves are said to be OUT OF PHASE. For the two waves in figure 69 the phase difference is 90°.

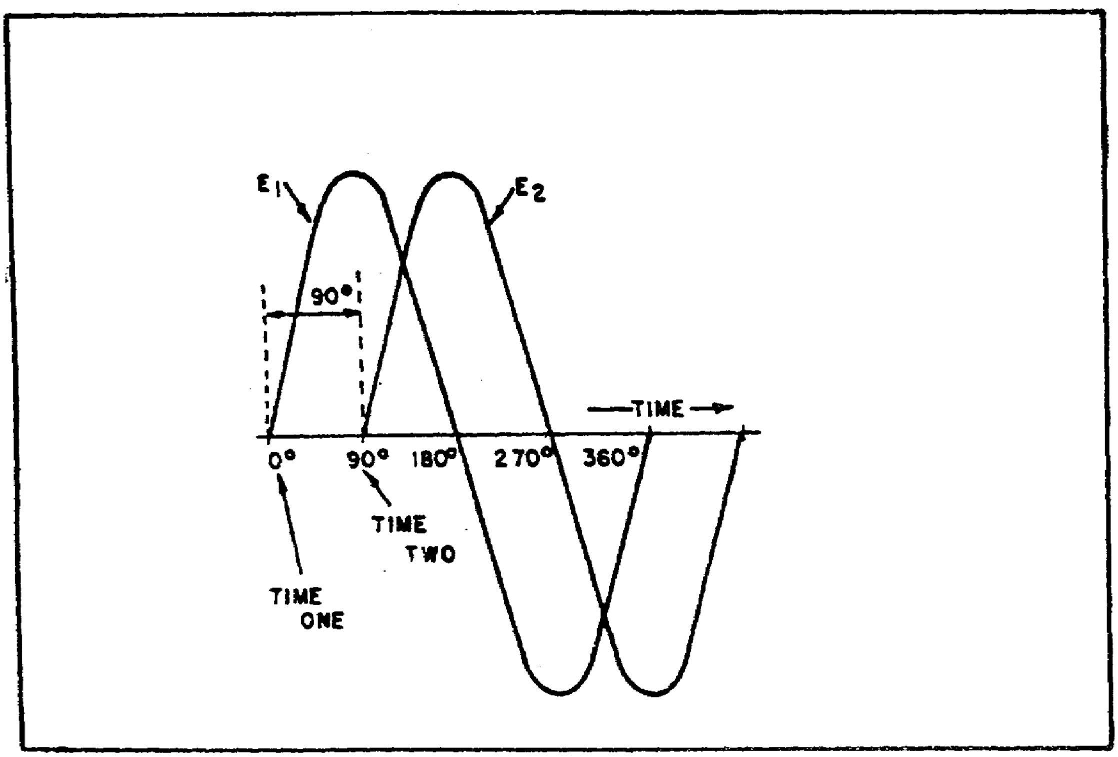


FIGURE 69. VOLTAGE WAVES 90° OUT OF PHASE.

To further describe the phase relationship between two sine waves, the terms LEAD and LAG are used. The amount by which one sine wave leads or lags another sine wave is measured in degrees. Refer again to figure 69. Observe that wave E_2 starts 90° later in time than does wave E_1. You can also describe this relationship by saying that wave E_1 leads wave E_2 by 90°, or that wave E_2 lags wave E_1 by 90°. Either statement is correct; it is the phase relationship between the two sine waves that is important.

It is possible for one sine wave to lead or lag another sine wave by any number of degrees, except. 0° or 360°. When the latter condition exists, the two waves are said to be in phase. Thus, two sine waves that differ in phase by 45° are actually out of phase with each other, whereas two sine waves that differ in phase by 360° are considered to be in phase with each other.

A phase relationship that is quite common is shown in Figure 70. Notice that the two waves illustrated differ in phase by 180°. Notice also that although the waves pass through their maximum and minimum values at the same time, their instantaneous voltages are always of opposite polarity. If two such waves exist across the same component, and the waves are of equal amplitude, they cancel each other. When they have different amplitudes, the resultant wave has the same polarity as the larger wave and has an amplitude equal to the difference between the amplitudes of the two waves.

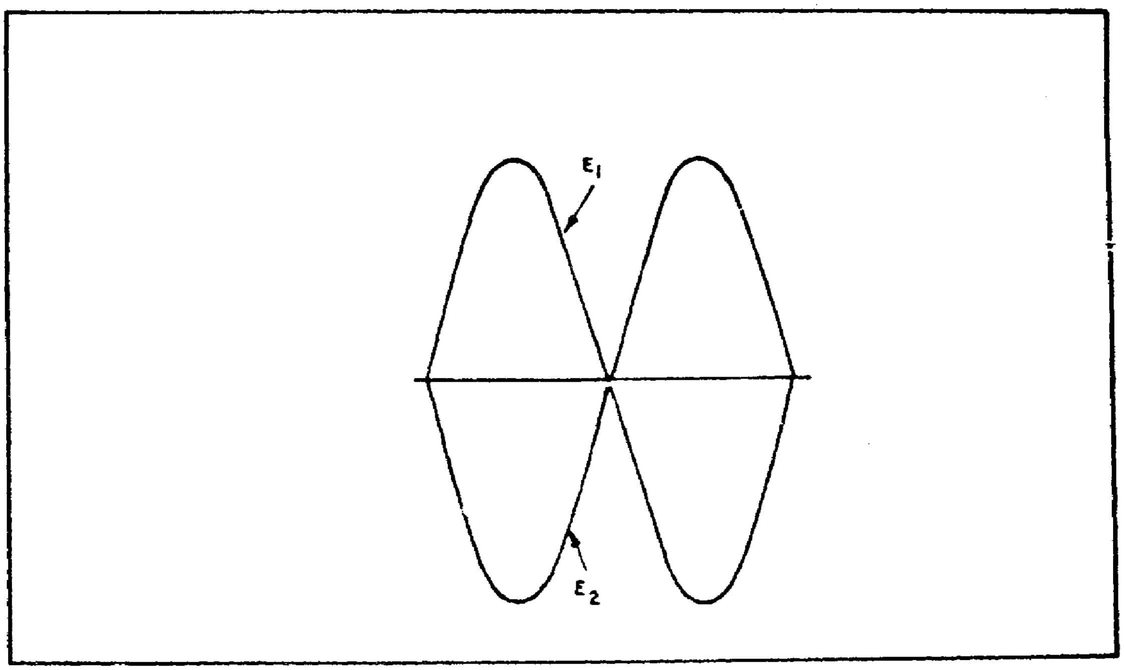


FIGURE 70. VOLTAGE WAVES 180° OUT OF PHASE.

To determine the phase difference between two sine waves, locate the points on the time axis traveling in the same direction. The number of degrees between the crossing points is the phase difference. The wave that crosses the axis at the later time (to the right of the time axis) is said to lag the other wave.

m. *Ohm's Law In AC Circuits*. Many ac circuits contain resistance only. The rules for these circuits are the same rules that apply to de circuits. Resistors, lamps, and heating elements are examples of resistive elements. When an .ac circuit contains only resistance, Ohm's Law, Kirchhoff's Law, and the various rules that apply to voltage, current, and power in a dc circuit also apply to the ac circuit. The Ohm's Law formula for an ac circuit can be stated as

$$I_{eff} = \frac{E_{eff}}{R} \text{ or } I = \frac{E}{R}$$

Remember, unless otherwise stated, all ac voltage and current values are given as effective values. The formula for Ohm's Law can also be stated as

$$I_{avg} = \frac{E_{avg}}{R} \text{ or } I_{max} = \frac{E_{max}}{R} \text{ or}$$

$$I_{peak\text{-}to\text{-}peak} = \frac{E_{peak\text{-}to\text{-}peak}}{R}$$

The important thing to keep in mind is: <u>DO NOT mix ac values</u>. When you solve for effective values, all values you use in the formula <u>must be effective</u> <u>values</u>. Similarly, when you solve for average values, all values you use <u>must be average values</u>.

This point should be clearer after you work the following problem: A series circuit consists of two resistors (R1 = 5 Ohms and R2 = 15 Ohms) and an alternating voltage source of 120 volts. What is I_{avg}?

Given: R1 = 5 Ohms
R2 = 15 Ohms
E_s = 120 volts

Solution: First solve for total resistance R_T.

R_T - R1 + R2
R_T - 5 Ohms + 15 Ohms
R_T = 20 Ohms

The alternating voltage is assumed to be an effective value (since it is not specified to be otherwise). Apply the Ohm's Law formula.

$$I_{eff} = \frac{E_{eff}}{R}$$

$$I_{eff} = \frac{120 \text{ volts}}{20 \text{ Ohms}}$$

$$I_{eff} = 6 \text{ amperes}$$

The problem, however, asked for the average value of current (I_{avg}). To convert the effective value of current to the average value of current, you must first determine the peak or maximum value of current, I_{max}.

$$I_{max} = 1.414 \times I_{eff}$$
$$I_{max} = 1.414 \times 6 \text{ amperes}$$
$$I_{max} = 8.484 \text{ amperes}$$

You can now find I_{avg}. Just substitute 8.484 amperes in the I_{avg} formula and solve for I_{avg}.

$$I_{avg} = 0.636 \times I_{max}$$
$$I_{avg} = 0.636 \times 8.484 \text{ amperes}$$
$$I_{avg} = 5.4 \text{ amperes (rounded off to one decimal place)}$$

Remember, you can use the Ohm's Law formulas to solve for any purely resistive ac circuit problem. Use the formulas in the same manner as you would to solve for a dc circuit problem.

6. Conclusion

In the preceding task, we discussed magnetism, analysis of inductive and capacitive circuits, and the production of alternating current. In the next task, we will discuss the basic fundamentals of semiconductors, including PNP and NPN transistors.

LESSON 1

ELECTRONIC PRINCIPLES

TASK 2. Describe basic fundamentals of semiconductors, including PNP and NPN transistors.

CONDITIONS

Within a self study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

Task one of this subcourse dealt with magnetism, analysis of inductive and capacitive circuits, and the production of alternating current. Task two will deal with semiconductor devices, including PNP and NPN transistors.

2. Solid-State Devices

Semiconductors have electrical properties somewhere between those of insulators and conductors. The use of semiconductor materials is not new; some devices are as old as the electron tube. Two of the most widely known semiconductors in use today are the JUNCTION DIODE and TRANSISTOR. These semiconductors fall under a more general heading called solid-state devices. A SOLID-STATE DEVICE is nothing more than an electronic device which operates by virtue of the movement of electrons with in a solid piece of semiconductor material.

Since the invention of the transistor, solid-state devices have been developed and improved at an unbelievable rate. Great strides have been made in the manufacturing techniques, and there is no foreseeable limit to the future of these devices. Solid-state devices made from semiconductor materials offer compactness, efficiency, ruggedness, and versatility. Consequently, these devices have invaded virtually every field of science and industry. In addition to the junction diode and transistor, a whole new family of related devices has been developed: the ZENER DIODE, LIGHT-EMITTING DIODE, FIELD EFFECT TRANSISTOR, etc. A more recent development that has dominated solid-state technology for the last decade, and probably has had a greater impact, on the electronics industry than either the electron tube or transistor, is the INTEGRATED CIRCUIT. The integrated circuit is a minute piece of semiconductor material that can produce complete electronic circuit functions.

As the applications of solid-state devices mount, the need for knowledge of these devices becomes increasingly important. Personnel in the Army today will have to understand solid-state devices if they are to become proficient in the repair and maintenance of electronic equipment.

a. *Application of Solid-State Devices*. Semiconductor devices are all around us. They can be found in a great variety of commercial products, from the family car to the pocket calculator. Semiconductor devices have found their way into television sets, portable radios, and stereo equipment.

Science and industry also rely heavily on semiconductor devices. Research laboratories use these devices in all sorts of electronic instruments to perform test, measurements, and numerous other experimental tasks. Industrial control systems (such as those used to manufacture automobiles) and automatic telephone exchanges also use semiconductors. Heavy-duty versions of the solid state rectifier diode are being used to convert large amounts of power for electric railroads. Of the many different applications for solid-state devices, space systems, computers, and data processing equipment are among the largest consumers.

The various types of modern military equipment are literally loaded with semiconductor devices. Many radars, communication, and much airborne equipment are transistorized. Data display systems, data processing units, computers, and aircraft guidance assemblies are all good examples of electronic equipment that use semiconductor devices. All of the specific applications of semiconductor devices would make a long and impressive list. The fact is, semiconductors are now being used extensively in commercial products, industry, and all branches of the armed services.

b. *Semiconductor Competition*. Semiconductor devices perform all the conventional functions of rectification, amplification, oscillation, timing, switching, and sensing. Simply stated, these devices perform the same basic functions of the electron tube but perform more efficiently, economically, and for a longer period of time. Therefore, these devices are used in place of electron tubes, and it is natural and logical to compare semiconductor devices with electron tubes.

Physically, semiconductor devices are much smaller than tubes. As can be seen in figure 71 on the following page, the difference is quite evident. This illustration shows some commonly used tube sizes. along-side semiconductor devices of similar capabilities. The reduction in size can be as great as 100: 1 by weight and 1000: 1 by volume. It is easy to see that size reduction favors the semiconductor device. Therefore, whenever miniaturization is required, or is convenient., transistors are favored over tubes. Bear in mind, however, that the extent of prtactical size reduction is a big factor; however, many things must he considered. Miniature electron tubes, for example, may be preferred in certain applications to transistors, thus keeping size reduction a competitive area.

Power is also a two-sided story. For low-power applications, where frequency is a significant factor, semiconductors have a decided advantage. This is true mainly because semiconductor devices perform very well with an extremely small amount of power; in addition, they require no filaments or heaters as in the case of the electron tube. For example, a computer operating with over 4000

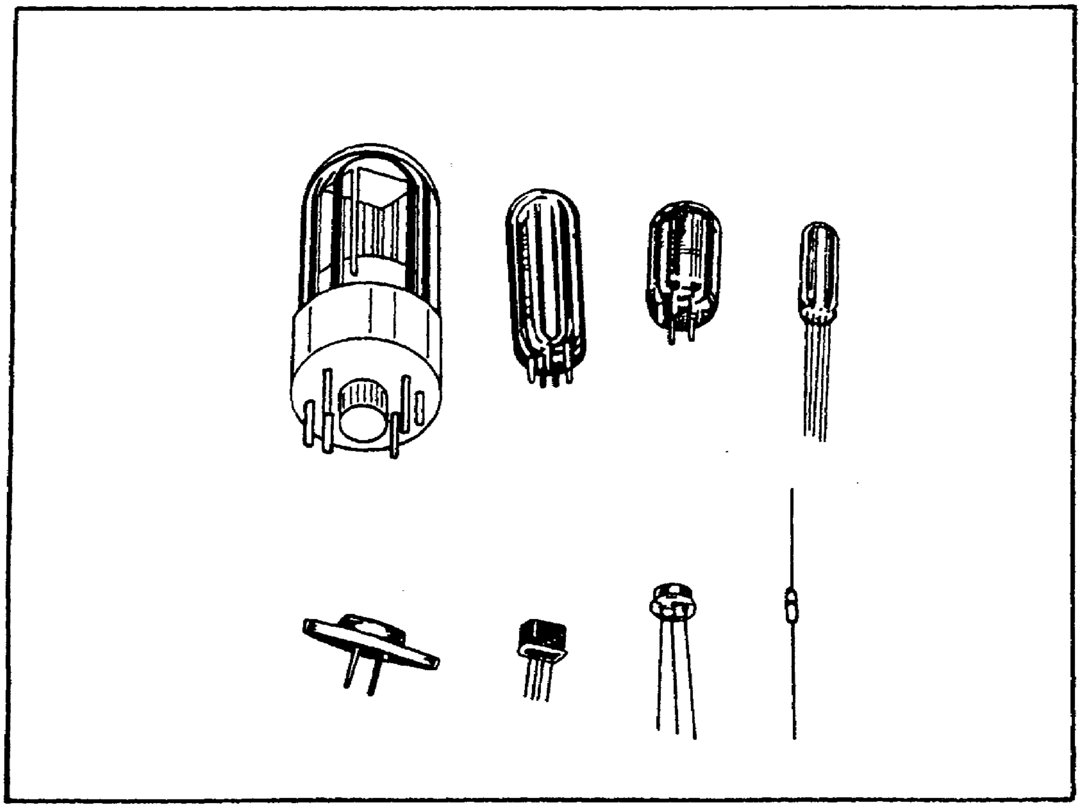


FIGURE 71. SIZE COMPARISONS OF ELECTRON TUBES AND SEMICONDUCTORS.

solid-state devices may require no more than 20 watts of power. However, the same number of tubes would require several kilowatts of power.

For high-power applications, it is a different story; tubes have the upper hand. The high-power electron tube has no equivalent in any semiconductor device. This is because a tube can be designed to operate with over a thousand volts applied to its plate, whereas the maximum allowable voltage for a transistor is limited to about 200 volts (usually 50 volts or less). A tube can also handle thousands of watts of power. The maximum power output for transistors generally ranges from 30 milliwatts to slightly over 100 watts.

When it comes to ruggedness and life expectancy, the tube is still in the competition. Design and functional requirements usually dictate the choice of devices. However, semiconductor devices are rugged and long-lived. They can be constructed to withstand impacts that would completely shatter an ordinary electron tube. Although some specially designed tubes render extensive service, the life expectancy of transistors is better than three to four times that of ordinary electron tubes. There is no known failure mechanism (such as an open filament in a tube) to limit the semiconductor's life. However, semiconductor devices do have some limitations. They are usually affected more by temperature, humidity, and radiation than tubes are.

c. *Semiconductor Theory*. To understand why solid-state devices function as they do, we will have to examine the composition and nature of semiconductors. This entails theory, which is fundamental to the study of solid--state devices.

(1) *Energy Bands*. Energy bands are groups of energy levels which result from the close proximity of atoms in a solid. The three most important energy bands are the CONDUCTION BAND, FORBIDDEN BAND, and VALENCE BAND. Each of these bands will be discussed briefly in the following paragraphs. While reading through these paragraphs refer to figure 72 on the following page.

(a) *Conduction Band*. The upper band in figure 72 is called the conduction band because electrons in this band are easily removed by the application of external electric fields. Materials that have a large number of electrons in the conduction band act as good conductors of electricity.

(b) *Forbidden Band*. Below the conduction band is the forbidden band or energy gap. Electrons are never found in this band, but may travel back and forth through it, provided they do not come to rest in the band.

(c) *Valence Band*. The last band or valence band is composed of a series of energy levels containing valence electrons. Electrons in this band are more tightly bound to the individual atom than the electrons in the conduction band. However, the electrons in the valence band can still be moved to the conduction band with the application of energy, usually thermal energy. There are more bands below the valence band but they are not important to the understanding of semiconductor theory and will not be discussed.

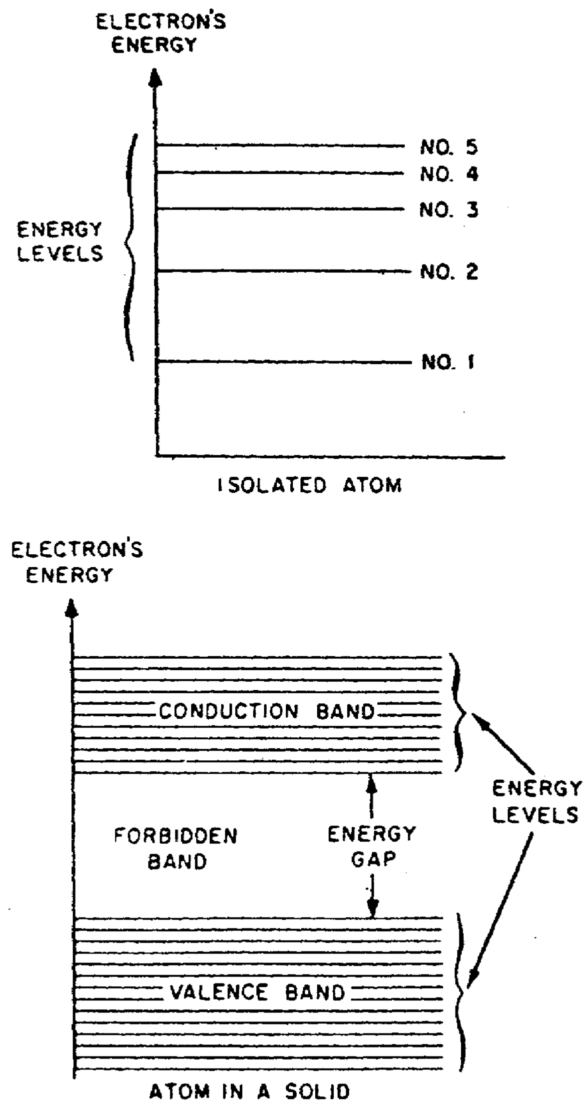


FIGURE 72. ENERGY ARRANGEMENT IN ATOMS.

(2) *Covalent Bonding*. Covalent bonding is the sharing of valence electrons between two or more atom . It is this bonding that holds the atoms together in an orderly structure called a CRYSTAL, (figure 73).

d. *Conduction Process*. The conduction process in a semiconductor is accomplished by two different types of current flow: HOLE FLOW and ELECTRON FLOW. Hole flow is very similar to electron flow except that holes (positive charges) move toward a negative potential and in an opposite direction to that of the electrons. In an INTRINSIC semiconductor (one which does not contain any impurities), the number of holes always equals the number of conducting electrons (figure 74 on the following page).

e. *Doping Process*. Doping is the process by which small amounts of selected additives, called impurities, are added to semiconductors to increase their current flow. Semiconductors which undergo this treatment are referred to as EXTRINSIC SEMICONDUCTORS (figure 75 on the following page).

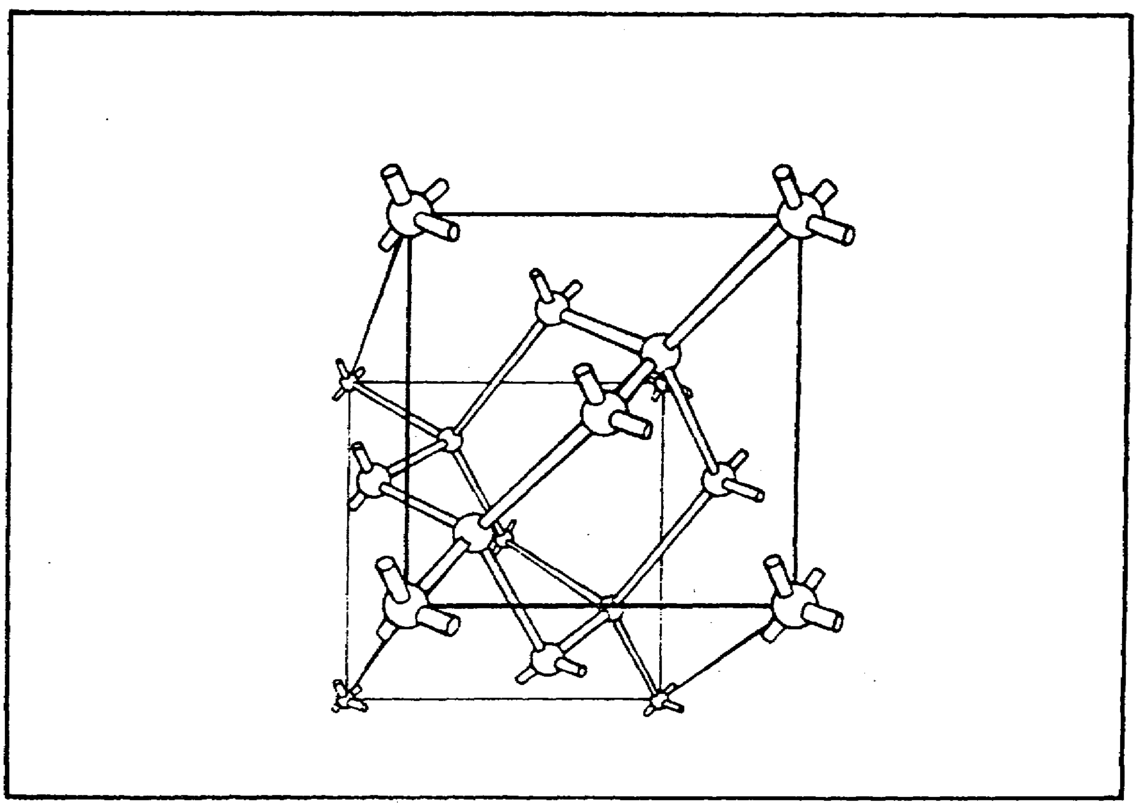


FIGURE 73. TYPICAL CRYSTAL STRUCTURE.

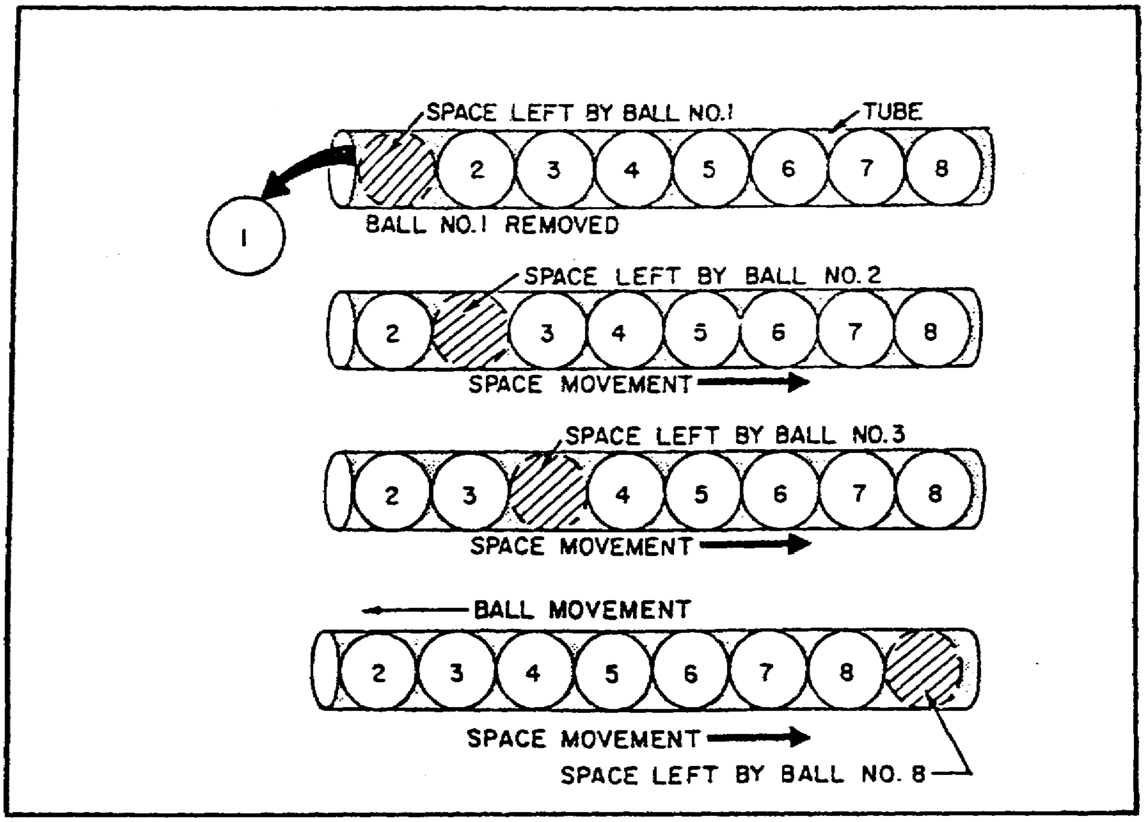


FIGURE 74. ANALOGY OF HOLE FLOW.

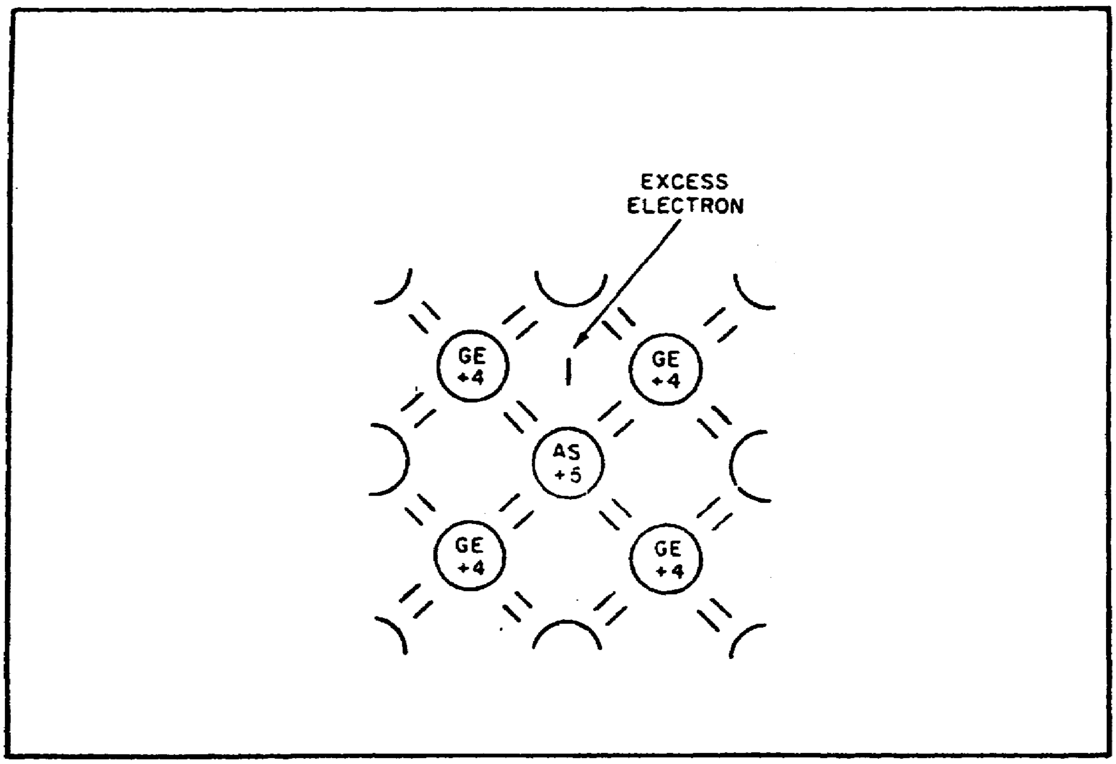


FIGURE 75. GERMANIUM CRYSTAL DOPED WITH ARSENIC.

f. *N-Type Semiconductor*. An N-type semiconductor is one which is doped with an N-type or donor impurity (an impurity that easily loses its extra electron to the semiconductor, causing it to have an excess number of free electrons). Since this type of semiconductor has a surplus of electrons, the electrons are considered the majority current carriers while the holes are the minority current carriers.

g. *P-Type Semiconductor*. A P-type semiconductor is one which is doped with a P-type or acceptor impurity (an impurity that reduces the number of free electrons causing more holes). The holes in this type semiconductor are the majority current carriers since they are present in the greatest quantity while the electrons are the minority current carriers.

h. *Semiconductor Diode*. The semiconductor diode, also known as a PN JUNCTION DIODE, is a two-element semiconductor device that makes use of the rectifying properties of a PN junction to convert alternating current into direct current by permitting current flow in only one direction (figure 76).

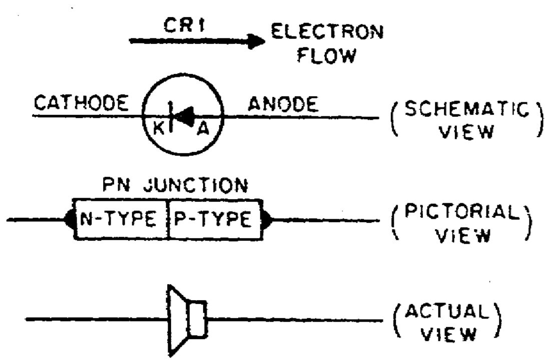


FIGURE 76. THE PN JUNCTION DIODE.

i. *PN Junction Construction*. A PN junction construction varies from one manufacturer to the next. Some of the more commonly used manufacturing techniques are: GROWN, ALLOY or FUSED-ALLOY, DIFFUSED, and POINT-CONTACT. Each of these

different techniques will be discussed briefly in the following paragraphs.

(1) *Grown*. In this method of manufacture, P-type and N-type impurities are mixed into a single crystal. By so doing, a P-region is grown over part of a semiconductor's length and an N-region is grown over the other part. This is called a GROWN junction and is illustrated in figure 77, view A.

(2) *Alloy or Fused-Alloy*. In this method, an impurity of one type is melted into a semiconductor of another type impurity. For example, a pellet of acceptor impurity is placed on a wafer of N-type germanium and heated. Under controlled temperature conditions, the acceptor impurity fuses into the wafer to form a P-region within it, as shown in view B of figure 77. This type of junction is known as an ALLOY or FUSED-ALLOW junction and is one of the most commonly used junctions.

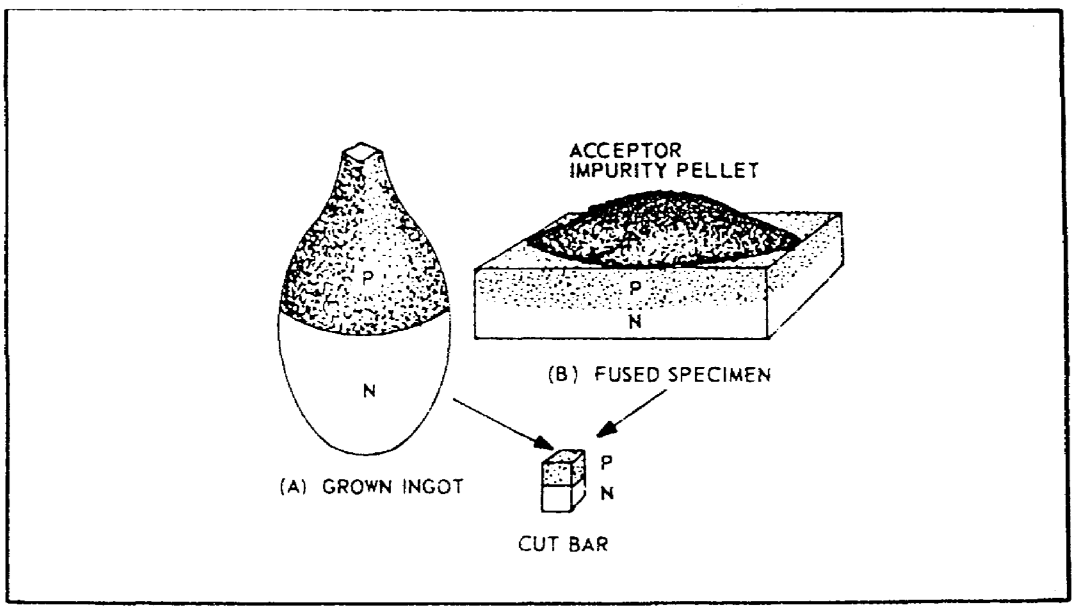


FIGURE 77. GROWN AND FUSED PN JUNCTIONS.

(3) *Point-Contact*. Figure 78 on the following page shown a POINT-CONTACT type of construction. It consists of a fine metal wire, called a cat whisker, that makes contact with a small amount of a N-type semiconductor as shown in view A of figure 78. The PN union is formed in this process by momentarily applying a high-surge current to the wire and the N-type semiconductor. The heat

generated by this current converts the material nearest the point of contact to a P-type material as shown in figure 78, view B.

j. *PN Junction Operation*. P- and N-type materials, how these materials are joined together to form a diode, and the function of the diode, have now been introduced. But before we can understand how the PN junction works, we must first consider current flow in the materials that make up the junction and then what happens initially within the junction when these two materials are joined together.

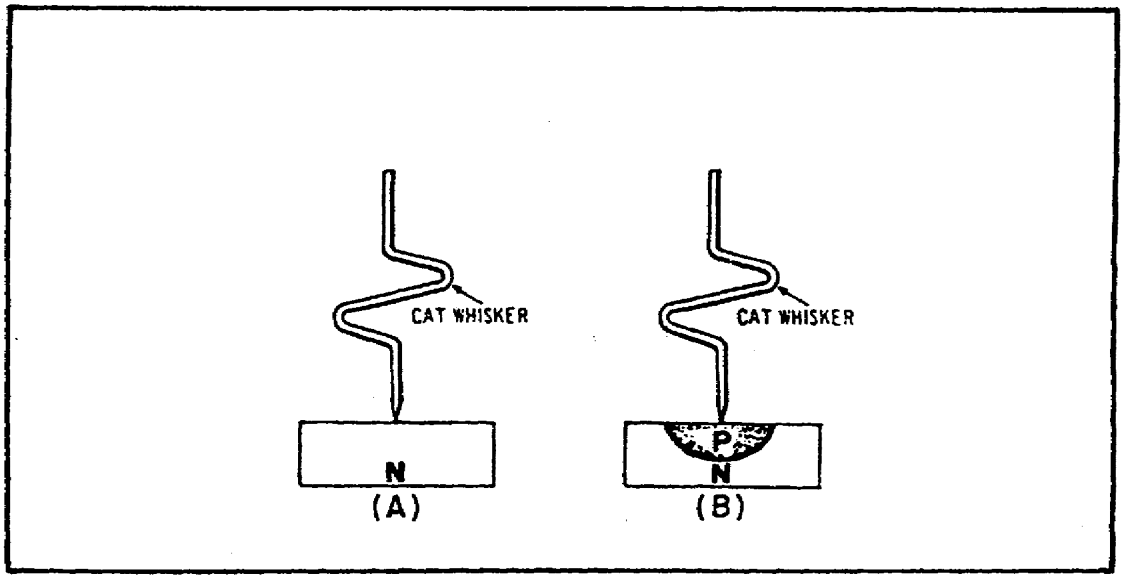


FIGURE 78. POINT-CONTACT TYPE OF DIODE CONSTRUCTION.

(1) *Current Flow in the N-Type Material*. Current flow in an N-type material is similar to conduction in a copper wire. That is, with voltage applied across the material, electrons will move through the crystal toward the positive terminal just as current flows in a copper wire (figure 79 on the following page).

(2) *Current Flow in the P-Type Material*. Current flow in a P-type material is by positive holes, instead of negative electrons. Unlike the electron, the hole moves from the positive terminal of the P material to the negative terminal (figure 80 on the following page).

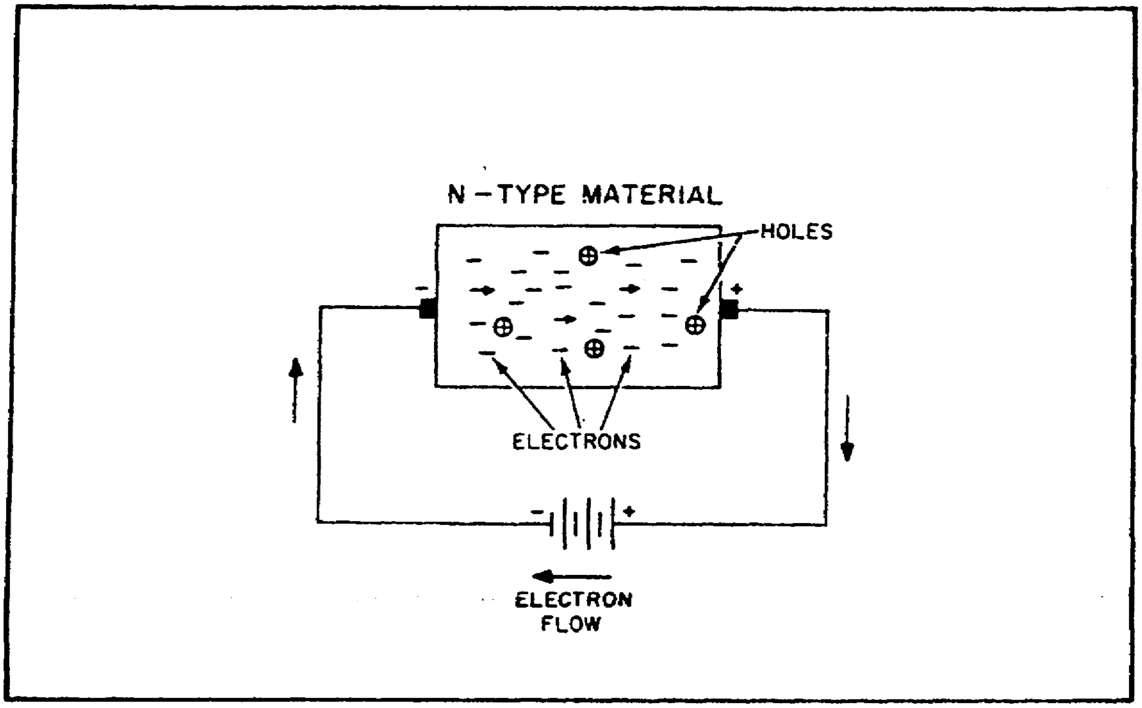


FIGURE 79. CURRENT FLOW IN THE N-TYPE MATERIAL.

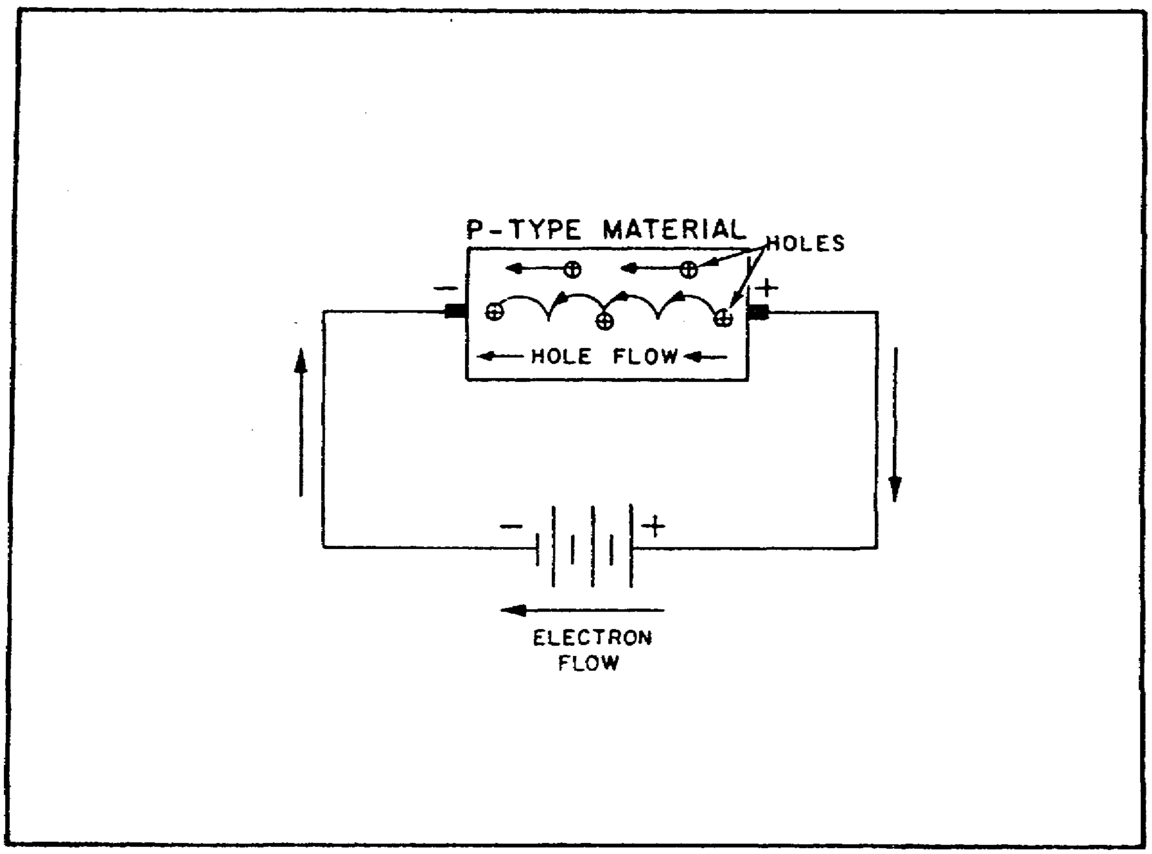


FIGURE 80. CURRENT FLOW IN THE P-TYPE MATERIAL.

(3) *Junction Barrier*. A junction barrier is an electrostatic field which has been created by joining a section of N material with a section of P material. Since holes and electrons must overcome this field to cross the junction, the electrostatic field is commonly called a BARRIER. Because there is a lack or depletion of free electrons and holes in the area around the barrier, this area has become known as the DEPLETION REGION-(figure 81).

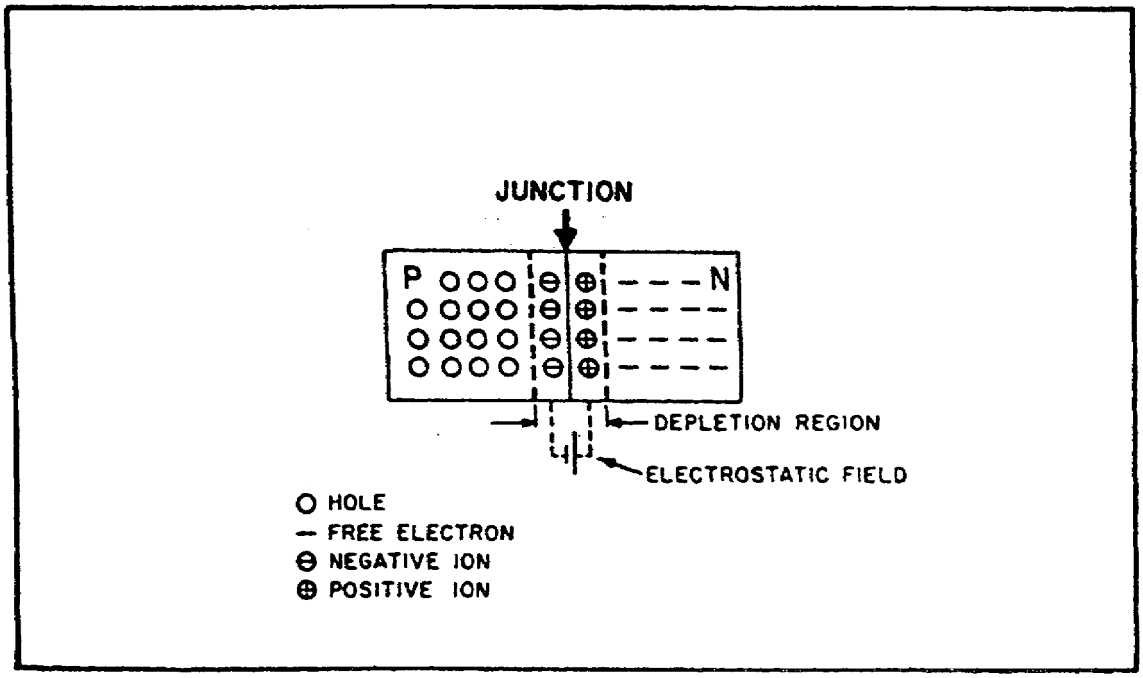


FIGURE 81. PN JUNCTION BARRIER FORMATION.

(a) *Forward Bias*. Forward bias is an external voltage which is applied to a PN junction to reduce its barrier and, therefore, aid current flow through the junction. To accomplish this function, the external voltage is connected so that it opposes the electrostatic field of the junction (figure 82 on the following page).

(b) *Reverse B*ias. Reverse bias is an external voltage which is connected across a PN junction so that its voltage aids the junction, thereby offering a high resistance to current flow through the junction (figure 83 on the following page).

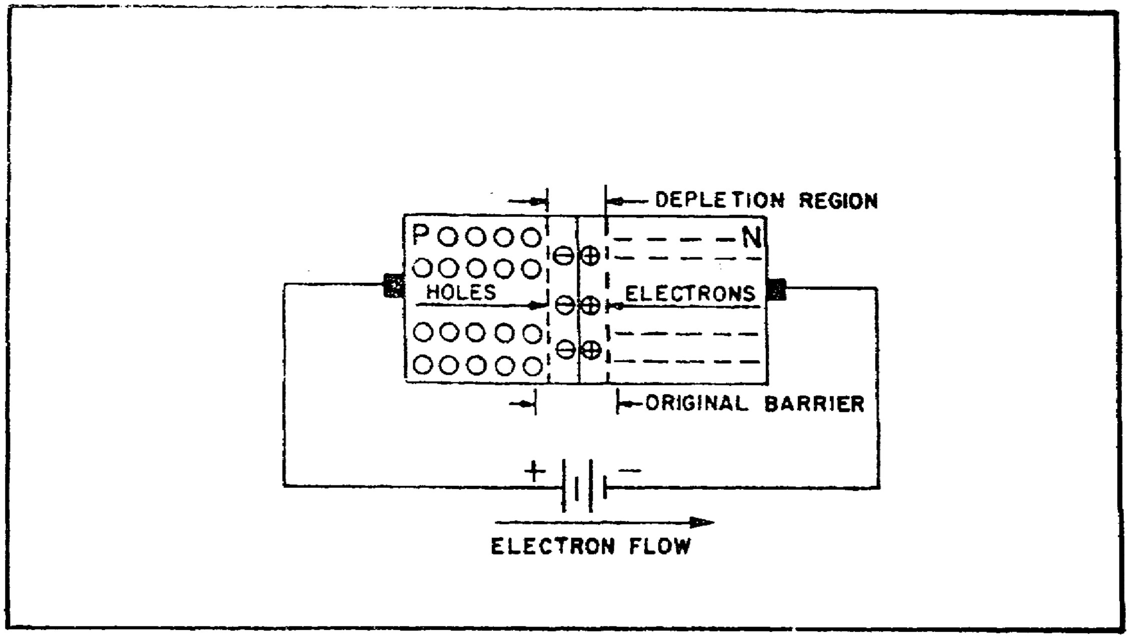


FIGURE 82. FORWARD-BIASED PN JUNCTION.

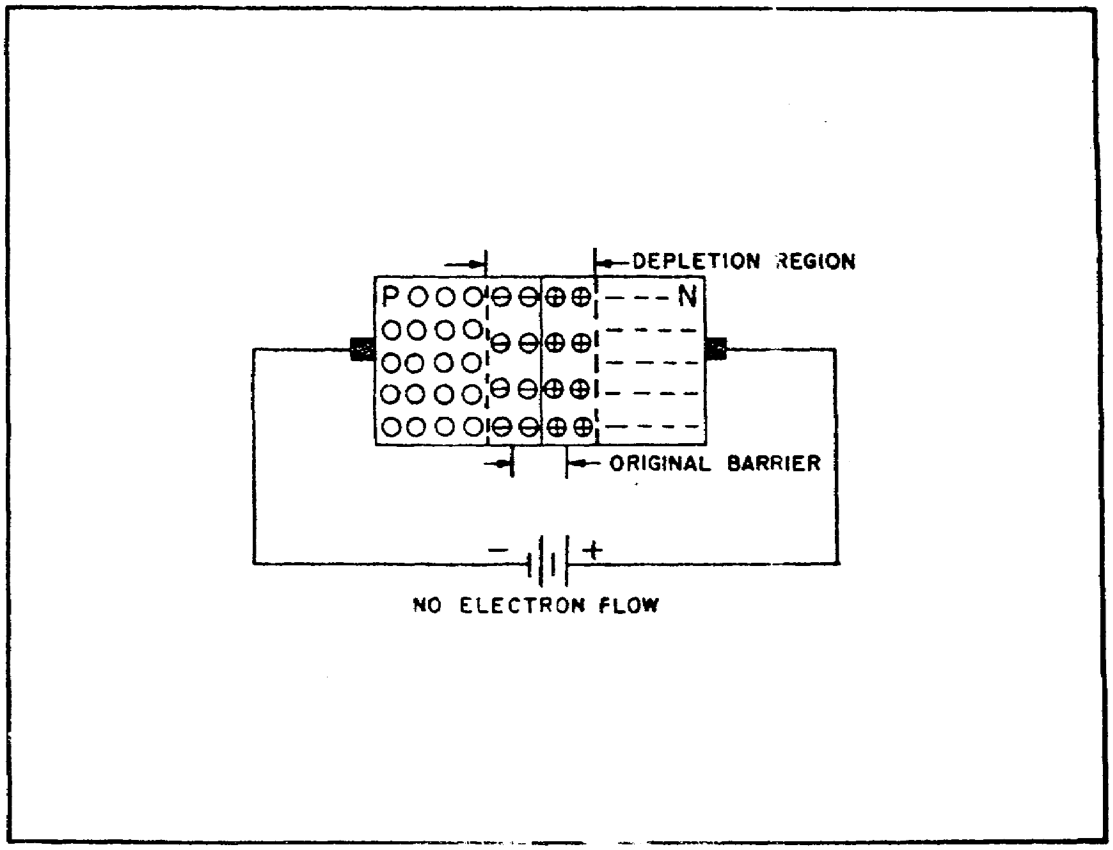


FIGURE 83. REVERSE-BIASED PN JUNCTION.

The PN junction has a unique ability to offer very little resistance to current flow in the forward-biased direction but maximum resistance to current flow when reverse biased. For this reason, the PN junction is commonly used as a diode to convert ac to dc. Figure {84 shows a plot of the voltage-current relationship (characteristic curve) for a typical PN junction diode.

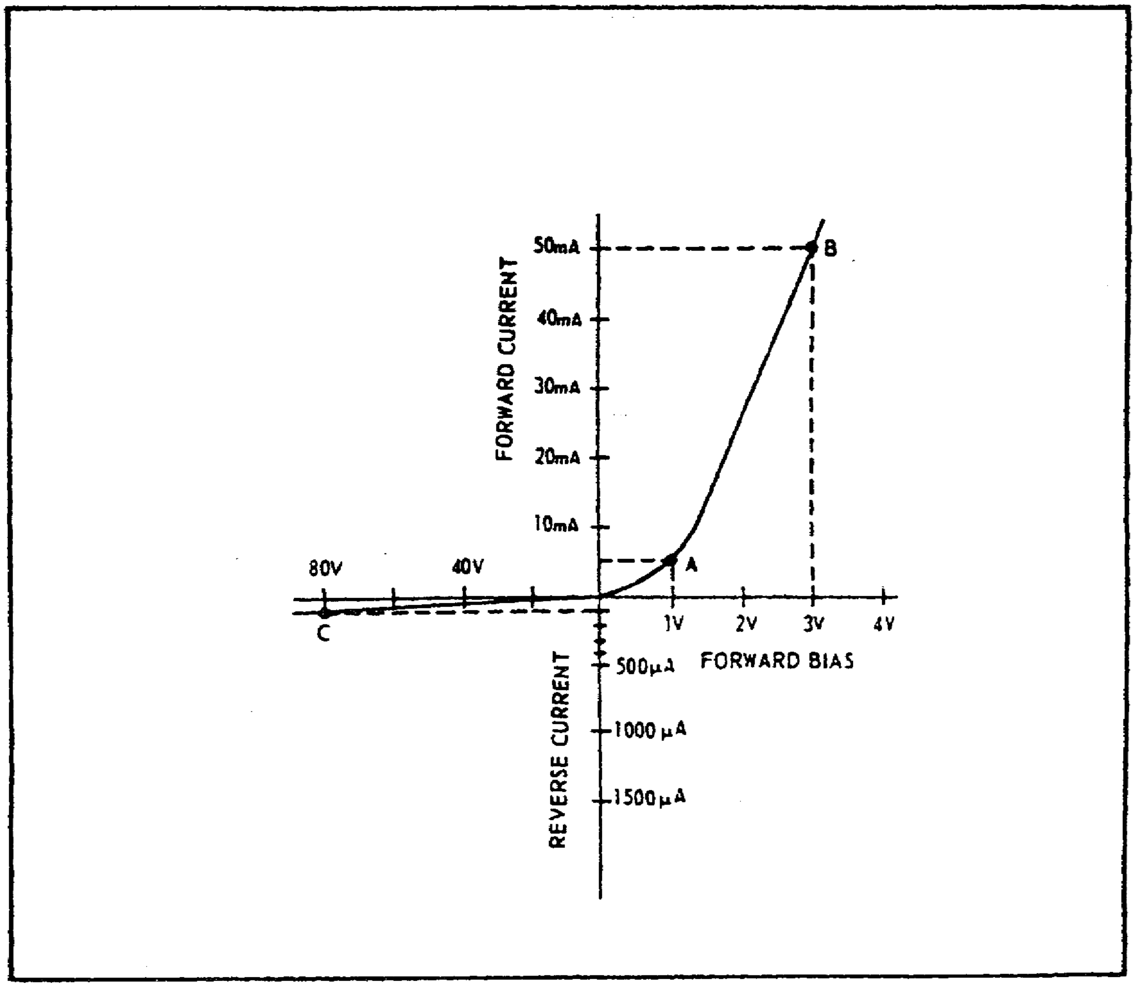


FIGURE 84. PN JUNCTION DIODE CHARACTERISTIC CURVE.

k. *PN Junction Application*. The PN junction's. application expands into many different areas, from a simple voltage protection device to an amplifying diode. Two of the most commonly used applications for the PN junction are the SIGNAL DIODE (mixing, detecting, and switching signals) and the RECTIFYING DIODE (converting ac to dc).

The metallic rectifier or dry-disc rectifier is a metal-to-semiconductor device that acts just. like a diode in that it permits current to flow more readily in one direction than the other. Metallic rectifiers are used in many applications where a relatively large amount of power is required. Figure 85 shows both metallic and half-wave rectifiers.

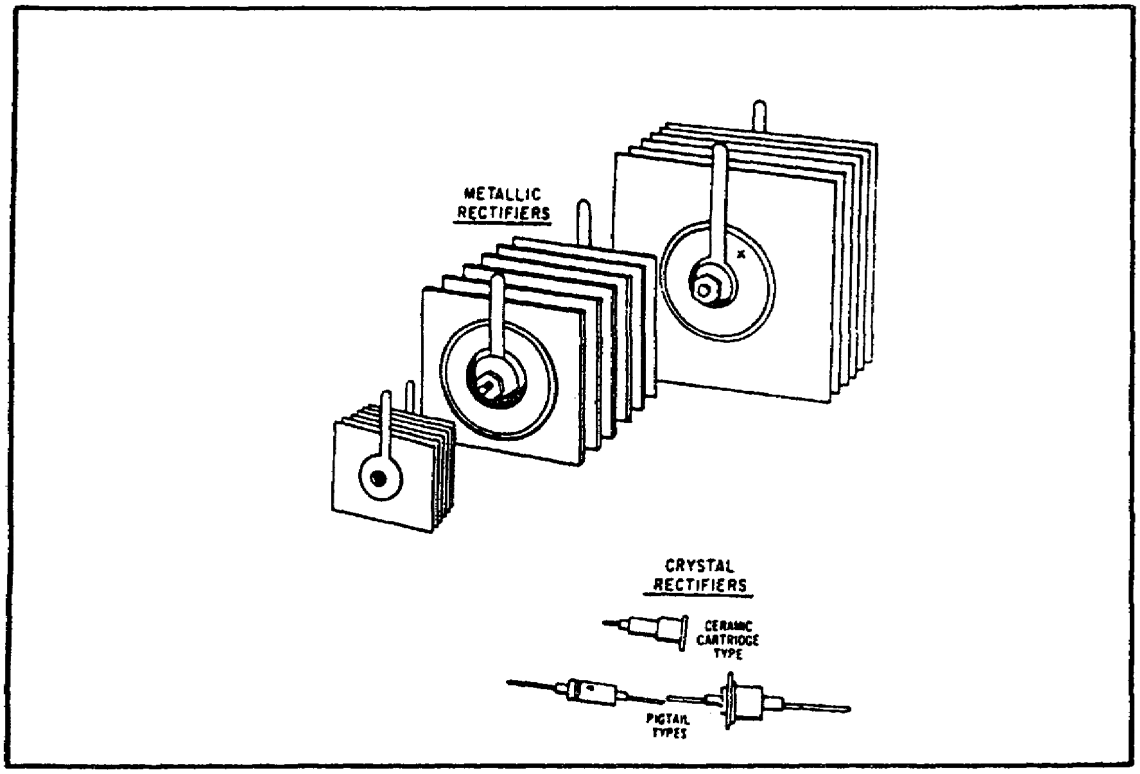


FIGURE 85. HALF-WAVE AND METALLIC RECTIFIERS.

l. *Diode Characteristics*. Diode characteristics are included in information supplied by manufacturers on different types of diodes, either in their manuals or on specification sheets.

Diode ratings are the limiting values of operating conditions of a diode. Operation of the diode outside its operating limits could damage the diode. Diodes are generally rated for: MAXIMUM AVERAGE FORWARD CURRENT, PEAK RECURRENT FORWARD CURRENT, MAXIMUM SURGE CURRENT, and PEAK REVERSE VOLTAGE.

m. *Diode Identification*. There are many different. types of diodes, varying in size from the size of a pinhead (used in subminiature circuitry) to large

250 ampere diodes (used in high power circuits). Because there are so many different types of diodes, some system of identification is needed to distinguish one diode from another. This is accomplished with the semiconductor identification system shown in figure 86.

XNYYY

XN YYY

COMPONENT IDENTIFICATION NUMBER

X - NUMBER OF SEMICONDUCTOR JUNCTIONS
N - A SEMICONDUCTOR
YYY - IDENTIFICATION NUMBER (ORDER OR REGISTRATION NUMBER) ALSO INCLUDES SUFFIX LETTER (IF APPLICABLE) TO INDICATE

1. MATCHING DEVICES
2. REVERSE POLARITY
3. MODIFICATION

EXAMPLE - IN345A (AN IMPROVED VERSION OF THE SEMICONDUCTOR DIODE TYPE 345)

FIGURE 86. SEMICONDUCTOR IDENTIFICATION CODE.

(1) *Semiconductor Identification System.* The semiconductor identification system is an alphanumerical code used to distinguish one semiconductor from another. It is used for diodes, transistors, and many other special semiconductor devices.

(2) *Diode Markings.* Diode markings are letters and symbols placed on the diode by manufacturers to distinguish one end of the diode from the other in some cases, an unusual shape or the addition of color code bands is used to distinguish the cathode

from the anode. Figure 87 shows some of the typical diode markings in use today.

(3) *Standard Diode Color Code System*. The standard diode color code system serves two purposes when it is used: (1) it identifies the cathode end of the diode, and (2) it also serves to identify the diode by number. Figure 88 (on the following page) shows the typical diode color code system.

n. *Diode Maintenance*. Diode maintenance consists of the procedures or methods used to keep a diode in good operating condition. To prevent diode damage, the standard diode safety precautions must be observed. Diodes must not be subjected to heat, current overloads, and excessively high operating voltages.

Testing a diode can be accomplished by using an ohmmeter, the substitution method, or a dynamic diode tester. The most convenient and quickest way of testing a diode is with an ohmmeter.

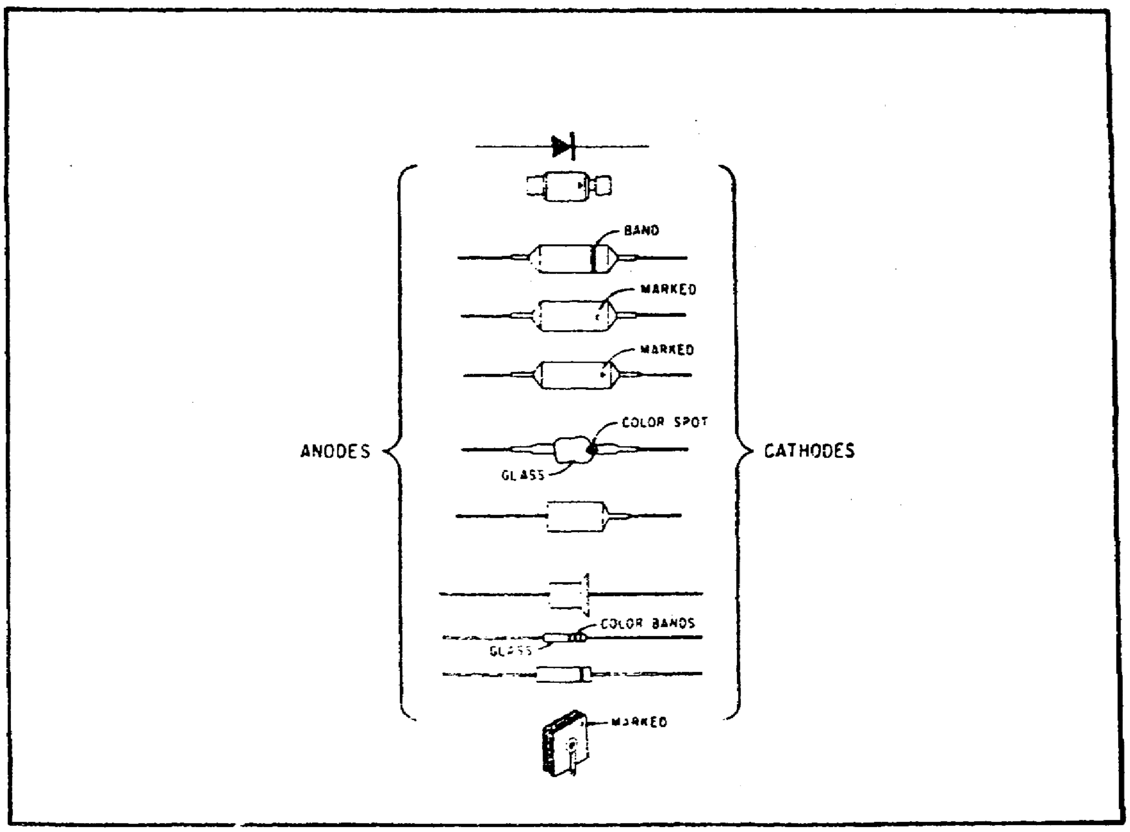
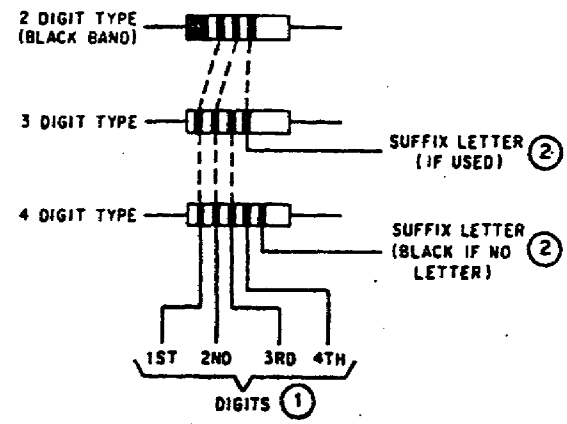


FIGURE 87. SEMICONDUCTOR DIODE MARKINGS.



COLOR	(1) DIGIT	(2) DIODE SUFFIX LETTER
BLACK	0	-
BROWN	1	A
RED	2	B
ORANGE	3	C
YELLOW	4	D
GREEN	5	E
BLUE	6	F
VIOLET	7	G
GRAY	8	H
WHITE	9	J
SILVER	-	-
GOLD	-	-
NONE	-	-

FIGURE 88. SEMICONDUCTOR DIODE COLOR CODE SYSTEM.

3. Transistors

The discovery of the first transistor in 1948 by a team of physicists at the Bell Telephone Laboratories sparked an interest in solid-state research that spread rapidly. The transistor, which began as a simple laboratory oddity, was rapidly developed into a semiconductor device of major importance. The transistor demonstrated for the first time in history that amplification in solids was possible. Prior to the transistor, amplification was achieved only with electron tubes. Transistors now perform numerous electronic tasks with new and improved transistor designs being continually put on the market. In many cases, transistors are more desirable than tubes because they are small, rugged, require no filament power, and operate at low voltages with comparatively high efficiency. The development of a family of transistors has even made possible the miniaturization of electronic circuits.

Transistors have infiltrated virtually every area of science and industry, from the family car to satellites. Even the military depends heavily on transistors. The ever increasing uses of transistors have created an urgent. need for sound and basic information regarding their operational.

a. *Transistor Fundamentals*. The first, solid state device discussed was the two-element semiconductor diode. The next device on our list is even more unique. It not only has one more element than the diode but it can <u>amplify</u> as well. Semiconductor devices that have three or more elements are called TRANSISTORS. The term transistor was derived from the words <u>TRANS</u>fer and res<u>ISTOR</u>. The term was adopted because it best describes the operation of' the transistor--the transfer of an input signal current from a low-resistance circuit to a high-resistance circuit. Basically, the transistor is a solid-state device that amplifies by controlling the flow of current carriers through its semiconductor materials.

There are many different types of transistors, but their basic theory of operation is all the same. The theory used to explain the operation of a transistor is the same as that theory used earlier with the PN-junction diode, except that two such junctions are required to form the three elements of a transistor.

b. *Elements of a Transistor*. The three elements of the two-junction transistor are:

(1) The EMITTER, which gives off, or "emits," current carriers (electrons or holes);

(2) The BASE, which controls the flow of current carriers; and

(3) The COLLECTOR, which collects the current carriers.

c. *Classification*. The two basic types of transistors are the negative-positive-negative (NPN) and the positive-negative-positive (PNP). The only difference in symbology between the two transistors is the direction of the arrow on the emitter. If the arrow points in, it is a PNP transistor and if it points outward, it is an NPN transistor.

d. Construction. The four transistor manufacturing processes are:

(1) Point contact;

(2) Grown or rate-grown junction;

(3) Alloy or fused junction; and

(4) Diffused junction.

Each of these types of manufacture will he discussed briefly in the following paragraphs.

Point-contact transistors are now practically obsolete. They have been replaced by junction transistors, which are superior to point-contact transistors in nearly all respects. The junction transistor generates less noise, handles more power, provides higher current and voltage gains, and can be mass-produced more cheaply than the point-contact transistor. Junction transistors are manufactured in much the same manner as the PN-junction diode discussed in paragraph 3i(1)(c) on pages 112 and 113 of this task. However, when the PNP or NPN material is grown, the impurity mixing process must be reversed twice in order to obtain the two junctions required in a transistor. Likewise, when the alloy-junction on or the diffused junction process is used, two junctions must also be created within the crystal.

e. *Transistor Theory*. The proper biasing of a transistor enables the transistor to be used as an amplifier. To function in this capacity, the emitter-to-base junction of the transistor is forward biased, while the base-to-collector junction is reverse biased.

f. *NPN Transistor Operation*. Just as is the case of the PN junction diode, the N material, comprising two end sections of the NPN transistor, contains a number of free electrons, while the center P section contains an excess number of holes. The action at each junction between these sections is the same as that previously described for the diode; that is, depletion regions develop and the junction barrier appears. In order to use the transistor as an amplifier, each of these junctions must be modified by some external bias voltage. For the transistor to function in this capacity, the first PN junction (emitter-base junction) is biased in the forward, or low-resistance, direction. At the same time, the second PN junction (base-collector junction) is biased in the reverse, or high-resistance, direction.

(1) *NPN Forward-braised Junction*. An important point to bring out at this time, one which was not mentioned during the explanation of the diode, is that the N material on one side of the forward-biased junction is more heavily doped than the P material. This results in more current being carried across the junction by the majority carrier electrons from the N material than the majority carrier from the material. Therefore, conduction through the forward-biased junction, as shown in figure 89 on the following page, is mainly by majority carrier electrons from the N material (emitter).

With the emitter-to-base junction in the figure biased in the forward direction, electrons leave the negative terminal of the battery and enter the N material, they pass easily through the emitter, cross over the junction, and combine with holes in the P material (base). For each electron that fills a hole in the P material, another electron will leave the P material (creating a new hole) and the positive terminal of the battery.

(2) *NPN Reverse-Biased Junction*. The second PN junction (base-to-collector), or reverse-biased junction as it is called (Figure 90 on page 126), blocks the majority (: current carriers from crossing the junction. However, there is a very small current that does pass through this junction. This current is called minority current or reverse current. This current is produced by the electron

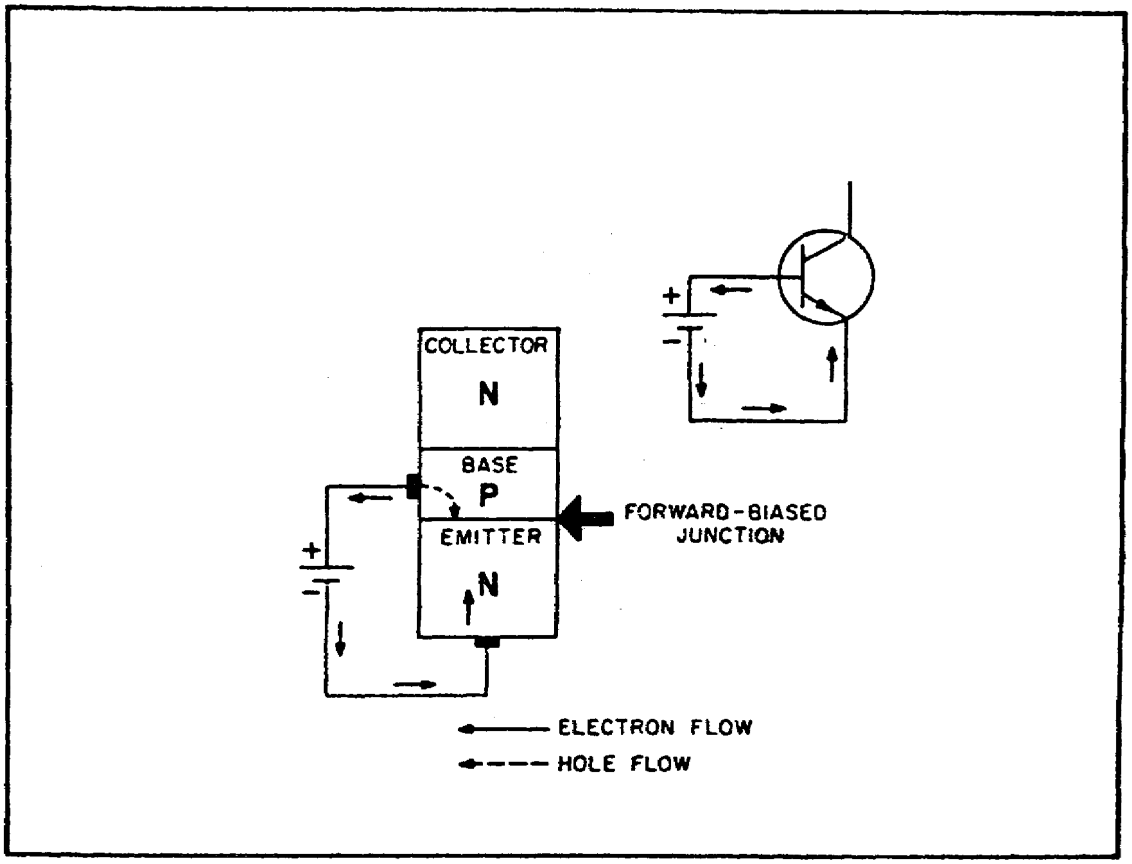


FIGURE 89. FORWARD-BIASED JUNCTION IN AN NPN TRANSISTOR.

hole pairs. The minority carriers for the reverse-biased PN junction are the <u>electrons</u> in the P material and the <u>holes</u> in the N material. These minority carriers actually conduct the current for the reverse-biased junction when electrons from the P material enter the N material, and the holes from the N material enter the P material. However, the minority current electrons play the most important part in the operation of the NPN transistor.

At this point it may be wondered why the second PN junction (base-to-collector) is not forward biased like the first PN junction (emitter-to-base). If both junctions were forward biased, the electrons would have a tendency to flow from each end section of the NPN transistor (emitter and collector) to the P section (base). In essence, we would have two junction diodes possessing a common base, thus eliminating any amplification and defeating the purpose of the transistor. A word of caution is -in order at this time. If the second PN junction is mistakenly biased in the forward direction, the excessive current could develop enough heat to destroy junctions, making the transistor useless. Therefore, be sure bias voltage polarities are correct before making any electrical connections.

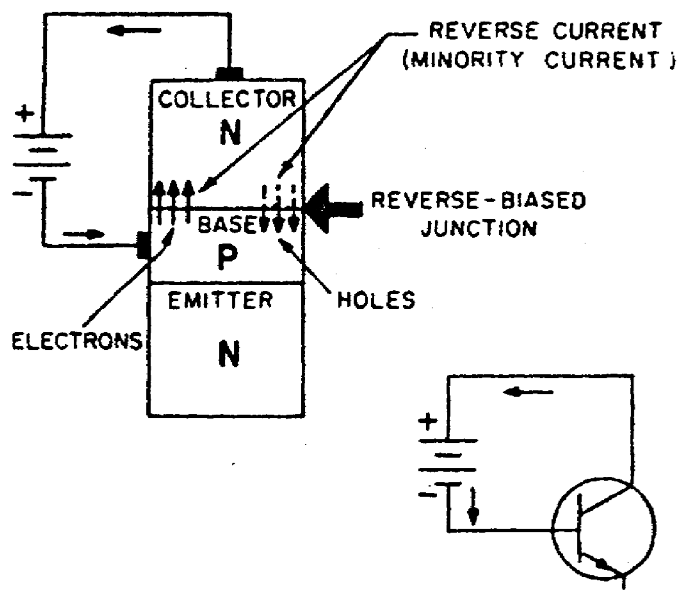


FIGURE 90. REVERSE-BIASED JUNCTION IN AN NPN TRANSISTOR.

(3) *NPN Interaction*. For a better understanding of just how the two junctions of the NPN transistor work together, refer to figure 91 on the following page.

The bias batteries in this figure have been labeled V_{CC} for the collector voltage supply, and V_{BB} for the base voltage supply. The base supply battery is quite small, as indicated by the number of cells in the battery, usually 1 volt or less. However, the collector supply is generally much higher than the base supply, normally around 6 volts. This difference in supply voltages is necessary in order to have current flow from the emitter to the collector.

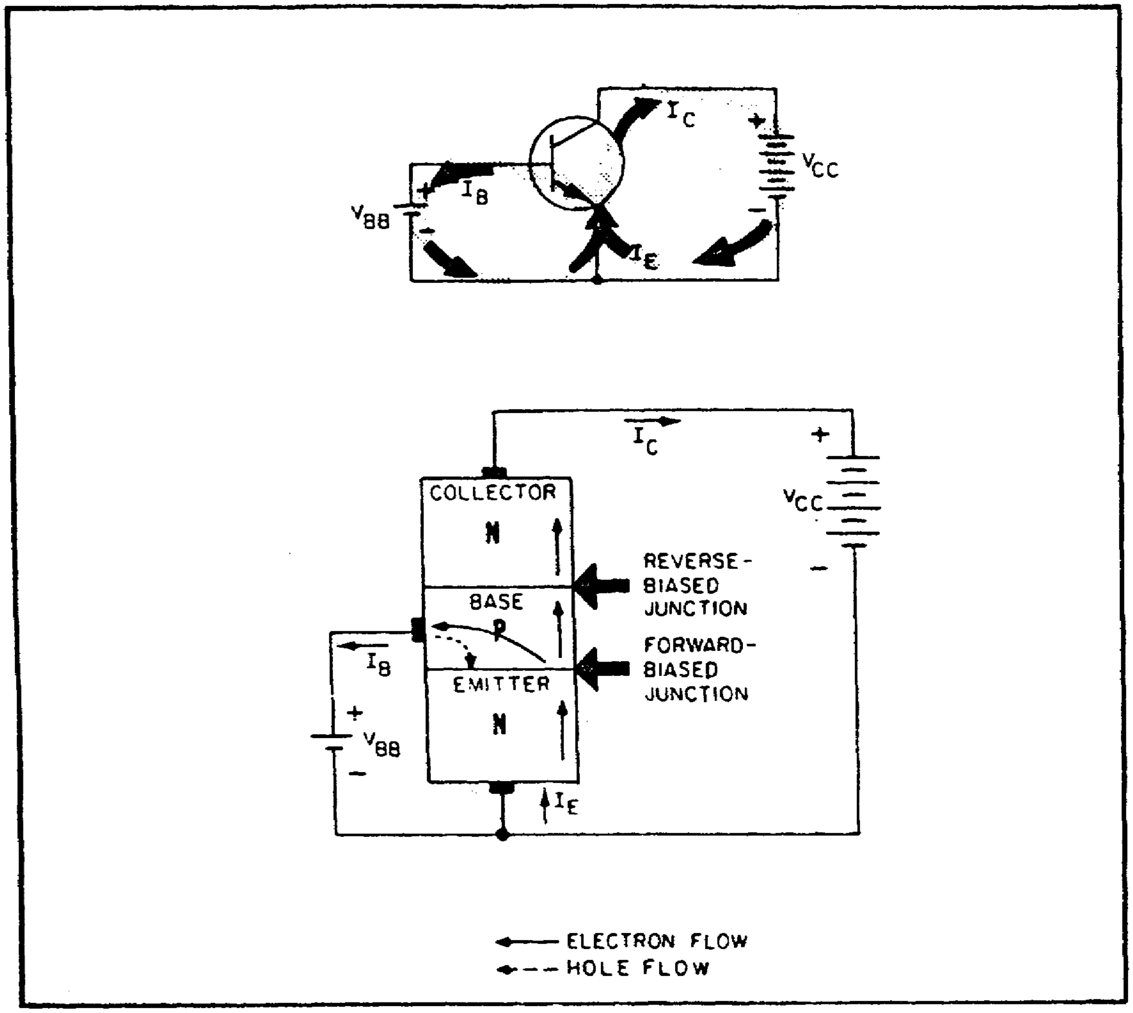


FIGURE 91. NPN TRANSISTOR OPERATION.

The current flow in the external circuit is always due to the movement of free electrons. Therefore, electrons flow from the negative terminals of the supply batteries to the N-type emitter. This combined movement of electrons is known as <u>emitter current</u> (I_E).

Because electrons are the majority carriers in the N material., they will move through the N material emitter to the emitter-base junction. With this junction forward biased, electrons continue on into the base region. Once the electrons are in the base, which is a P-type material, they become minority carriers. Some of the electrons that move into the base recombine with available holes, For each electron that recombines, another electron moves out through the base lead as base current I_B

(creating a new hole for eventual combination) and returns to the base supply battery V_{BB}. The electrons that recombine are lost as far as the collector is concerned. Therefore, in order to make the transistor more efficient, the base region is made very thin and lightly doped. This reduces the opportunity for an electron to recombine with a hole and be lost. Thus, most of the electrons that move into the base region come under the influence of the large collector reverse bias. This bias acts as forward bias for the minority carriers (electrons) in the base and, as such, accelerates them through the base-collector junction and on into the collector region. Since the collector is made of an N-type material, the electrons that reach the collector again become majority current carriers. Once in the collector, the electrons move easily through the N material and return to the positive terminal of the collector supply battery V_{CC} as collector current (I_C).

To further improve the efficiency of the transistor, the collector is made physically larger than the base for two reasons:

(a) To increase the chance of collecting carriers that diffuse to the side, as well as directly across the base region, and

(b) To enable the collector to handle more heat without damage.

In summary, total current flow in the NPN transistor is through the emitter lead. Therefore, in terms of percentage, 1_E is 100 percent. On the other hand, since the base is very thin and lightly doped, a smaller percentage of the total current (emitter current) will flow in the base circuit than in the collector circuit. Usually no more than 2 to 5 percent of the total current is base current (I_B) while the remaining 95 to 98 percent is collector current (I_C). A very basic relationship exists between these two currents:

$$I_E = I_B + I_C$$

In simple terms this means that the emitter current is separated .into base and collector current. Since the amount of current leaving the emitter is solely a function of the emitter-base bias, and because the collector receives most of this current, then a small change in emitter-base bias

will have a far greater effect on the magnitude of collector current than it will have on base current. In conclusion, the relatively small emitter-base bias controls the relatively large emitter-to-collector current.

g. *PNP Transistor Operation*. PNP transistor operation is essentially the same as the NPN operation except the majority current carriers are holes and the bias batteries are reversed. Figure 92 shows a typical bias setup for the PNP transistor.

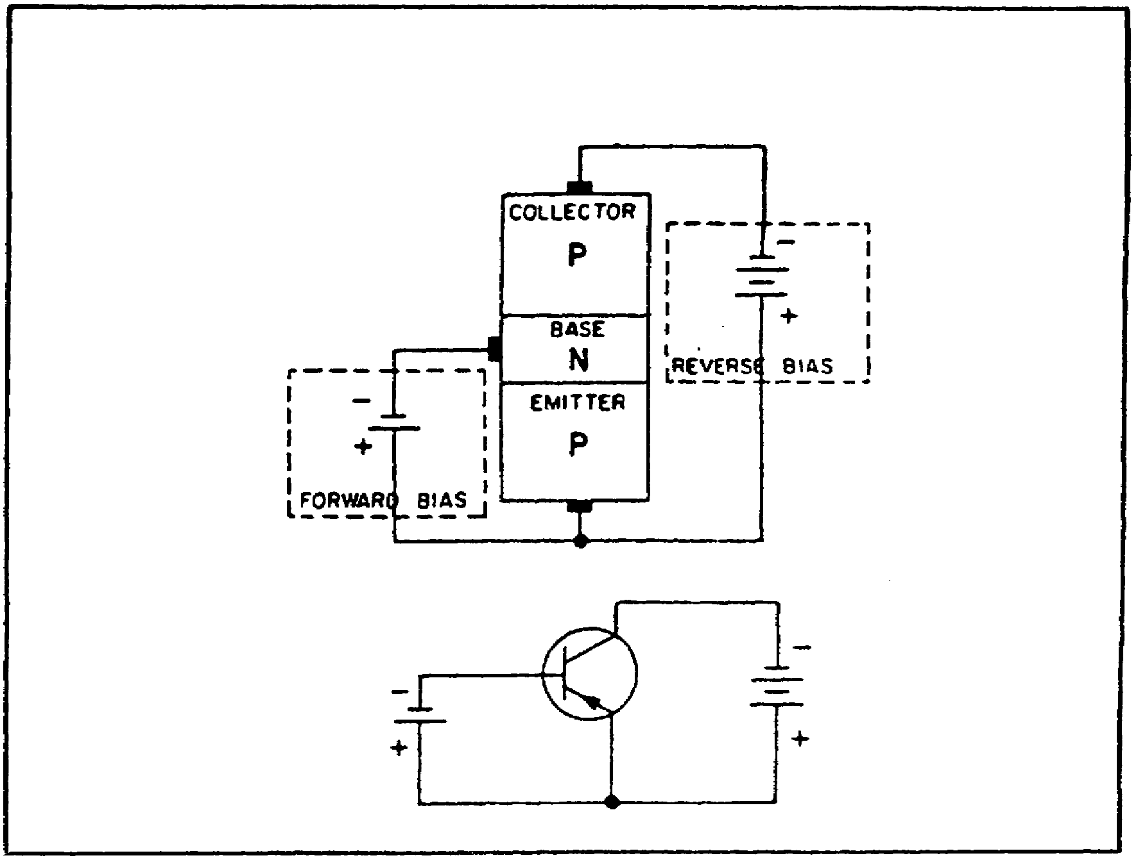


FIGURE 92. PROPERLY BIASED PNP TRANSISTOR.

(1) *PNP Forward-Biased Junction*. What happens when the emitter-base junction in figure 93, on the following page, is forward biased. With the bias setup shown, the positive terminal of the battery repels the emitter holes toward the base, while the negative terminal drives the base electrons toward the emitter. When an emitter hole and a base

electron meet, they combine. For each electron that combines with a hole, another electron leaves the negative terminal of the battery, and enters the base. At the same time, an electron leaves the emitter, creating a new hole, and enters the positive terminal of the battery. This movement of electrons into the base and out of the emitter constitutes base current flow (I_B), annd the path these electrons take is referred to as the emitter-base circuit.

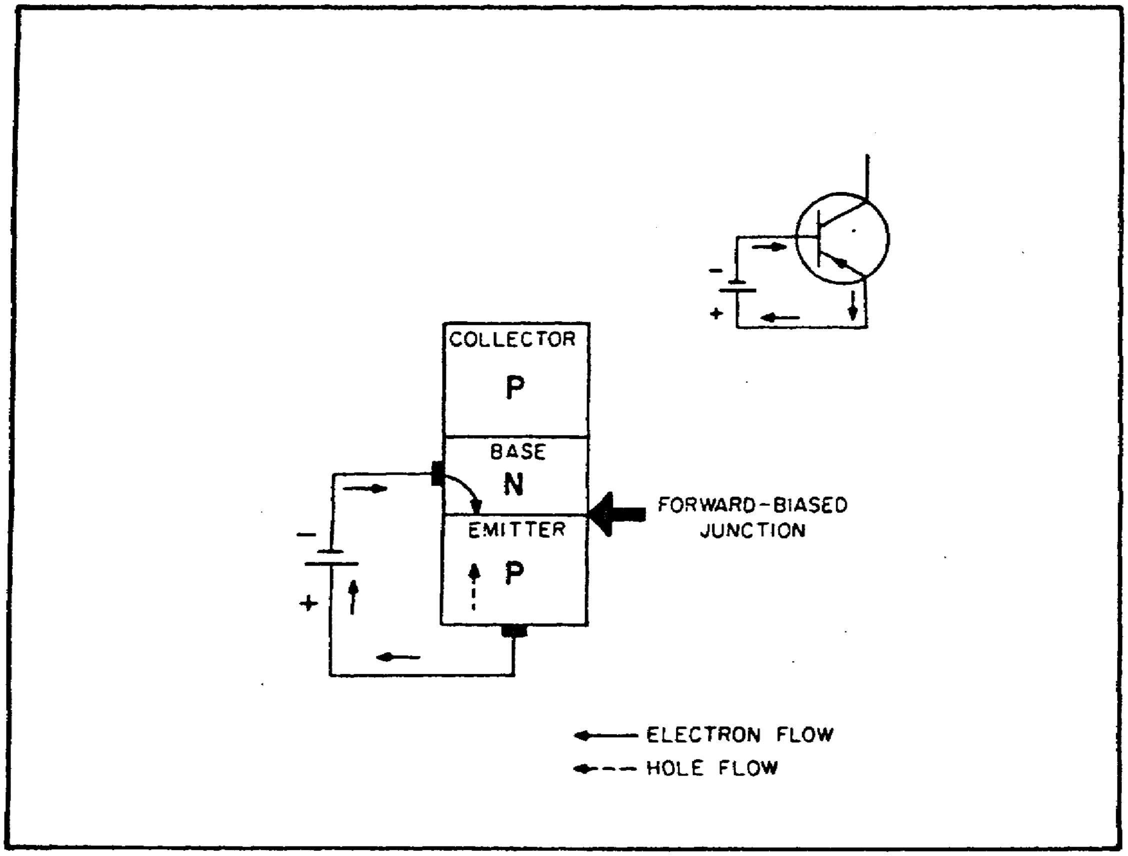


FIGURE 93. FORWARD-BIASED JUNCTION IN A PNP TRANSISTOR.

(2) PNP Reverse-Biased Junction. In the reverse--biased junction (figure 94 on the following page), the negative voltage on the collector and the positive voltage on the base, block the majority current carriers from crossing the junction. However, this same negative collector voltage acts as forward bias for the minority current holes in the base, which cross the junction and the enter the collector. The-minority current electrons in the collector react to forward bias the positive base voltage- and move into the base.

The holes in the collector are filled by electrons that flow from the negative terminal of the battery, other electrons in the base break their covalent bonds and enter the positive terminal of the battery. Although there is only minority current flow in tile reverse-biased junction, it is still very small due to the limited number of minority current carriers.

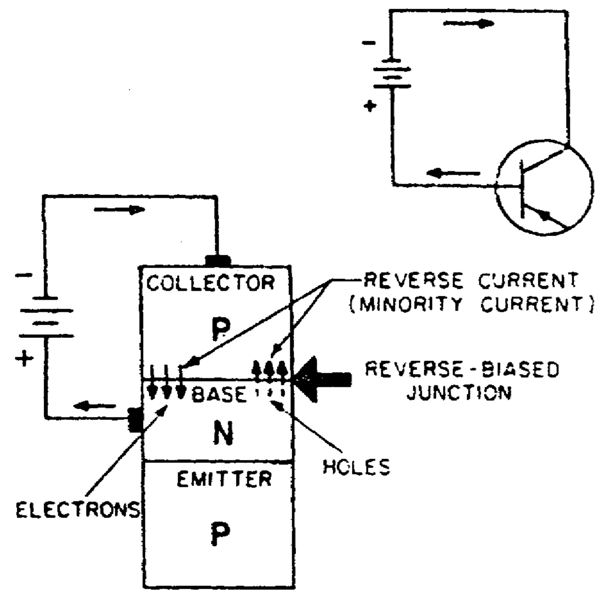


FIGURE 94. REVERSED-BIASED JUNCTION IN A PNP TRANSISTOR.

(3) *PNP Junction Interaction.* The interaction between the forward- and reverse-biased junctions in a PNP transistor is very similar to that in an NPN transistor, except that in the PNP transistor, the majority current. carriers are holes. In the PNP transistor shown in figure 95 on the following page, the positive voltage on the emitter repeats the holes toward the base. Once in the base, the holes combine with the base electrons. However, the base region is made very thin to prevent the recombination of holes with electrons. Therefore, well over 90 percent of the holes that enter the base become attracted to the large negative collector voltage rand pass right through the base. However, for each electron and hole that combine in the base region, another electron leaves the negative terminal of the base battery (V_{BB}} and

enters the base as base current (I_{BB}). At the same time, an electron leaves the negative terminal of the battery, another electron leaves the emitter as I_E (creating a new hole) and enters the positive terminal of V_{BB}. Meanwhile, in the collector circuit, electrons from the collector battery (V_{CC}) enter the collector as I^C and combine with the excess holes from the base. For each hole that is neutralized in the collector by an electron, another electron leaves the emitter and starts its way back to the positive terminal of V_{CC}.

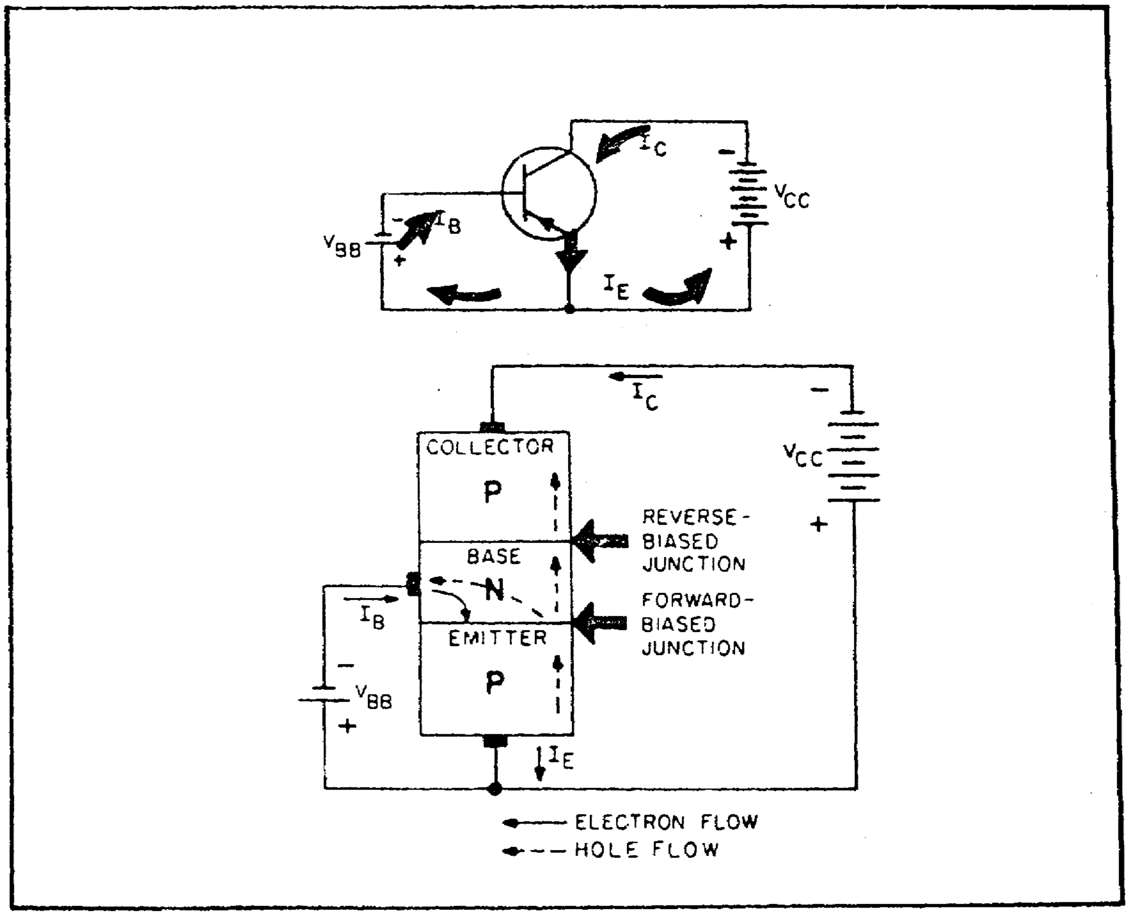


FIGURE 95. PNP TRANSISTOR OPERATION.

Although current flow in the external circuit of the PNP transistor is opposite in direction to that of the NPN transistor, the majority carriers always flow from the emitter to the collector. This flow of majority carriers also results in the formation of two individual current loops within each transistor. One loop is the base-current path and the other loop the collector current path. The combination of the current in both of these loops (I_B + I_C) results in total transistor current (I_E). The most important thing to remember about the two different types of transistors is that the emitter-base voltage of the PNP transistor has the same controlling effect on collector current as that of the NPN transistor. In simple terms, increasing the forward bias voltage of a transistor reduces the emitter-base junction barrier. This action allows more carriers to reach the collector causing an increase in current flow from the emitter to the collector and through the external circuit. Conversely, a decrease in the forward-bias voltage reduces collector current.

4. Conclusion

In this task, we covered the basic fundamentals of semiconductor devices, including NPN and PNP transistors. In the next task, we will cover the setup, operation, and use of the AN/USM-281C oscilloscope.

LESSON 1

ELECTRONIC PRINCIPLES

TASK 3. Describe the AN/USM-281C oscilloscope; including setup, operation, and use.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

In the previous two tasks of this subcourse, we covered a wide area of information concerning electronic principles. This information and the information covered in subcourse 0D1633 is extremely important to the 421A, Armament Repair Technician, as it is for anyone working in one of the Army's various MOSs that deal with electricity and electronics. However, this information does absolutely no good if the person armed with it cannot use the necessary test equipment to find the cause of malfunctions and to check for proper operation.

The purpose of this task is to introduce the student to the AN/USM--281C oscilloscope. In the following paragraphs, we will cover what the oscilloscope is, how it is setup, the proper operating procedures, and its use.

2. AN/USM-281C Oscilloscope

a. *Equipment Description.* The oscilloscope is a light-weight, solid-state instrument designed for the general purpose of waveform measurements using single- or dual-trace displays with normal or delayed sweep. It consist s of the oscilloscope OS-245(P)/U (main frame), the oscilloscope vertical amplifier plug-in unit, AM-6565/U (vertical amplifier, two required), the oscilloscope dual time base plug-in unit, TD-1085/U (dual time base), and the instrument cover and accessory group. These units are described in the following paragraphs. Figure 96 shows an overall view of the AN/USM-281C oscilloscope.

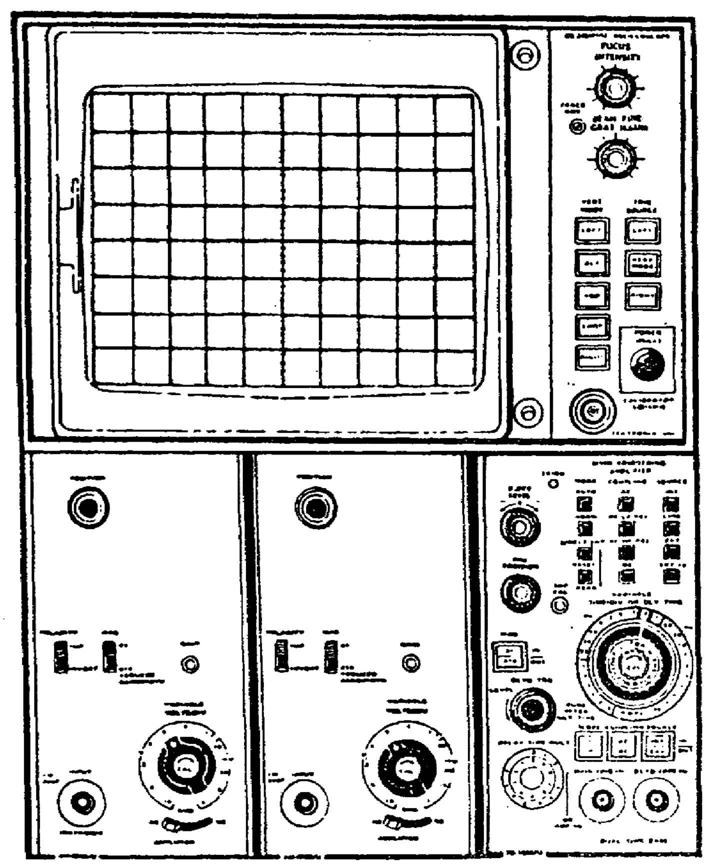


FIGURE 96. AN/USM-281C OSCILLOSCOPE

(1) Main Frame. The main frame contains the display and power supply components and provides three plug-in compartments for the vertical amplifiers and the dual time base plug-in units. Use of a rugged, large scan, 6.5 inch cathode ray tube (crt) provides for a large, bright display with small spot size, fast writing speed, and high reliability. The illuminated graticule is 8 by 10 divisions in size (each division is 1 centimeter (cm)), and provides for 2 centimeters of linear overscan in each axis. Of the three plug-in compartments, the two on the left are connected to the vertical deflection circuits and the one on the right is connected to the horizontal deflection system. Electronic switching between the vertical amplifiers allows a dual-trace vertical display. The vertical amplifier can also be used in the horizontal axis compartment for calibrated x-y displays. The main frame vertical amplifier circuits bandwidth is greater than 100 megahertz. Regulated dc power supplies ensure that oscilloscope performance is not affected by variations in line voltage or frequency, or by changes in the load caused by varying power requirements.

(2) *Vertical Amplifier*. The vertical amplifier is a wide-band amplifier (dc to 50 megahertz) that provides vertical deflection signals to the main frame vertical amplifier circuits. Constant bandwidth is provided over all of the deflection factor settings with each setting selectable for either calibrated or uncalibrated operation. Display polarity is also selectable, as is the magnification factor. Use of two vertical amplifier compartments in the main frame allows one amplifier to be used alone for single-trace operation, or two amplifiers to be used for dual-trace operation. The vertical amplifier can also be used in the main frame horizontal axis compartment for calibrated x-y display purposes.

(3) *Dual Time Base*. The dual time base provides horizontal deflection signals to the main frame crt circuits for each of two traces in any four display modes:

(a) Normal,

(b) Intensified delaying,

(c) Delayed, and

(d) Amplifier.

Either calibrated or uncalibrated operation may be selected in any mode. In the normal sweep mode, only the main sweep operates. In intensified delaying sweep mode, the main sweep is intensified only during the period set for the delayed sweep, with the position intensified portion adjustable to any point on the main sweep. In the delayed sweep mode, the intensified portion of main sweep is displayed over the full 10 centimeters of the graticule area. In amplifier mode, the horizontal amplifier can be used for x-y displays or for an externally applied sweep signal.

(4) *Cover*. The instrument cover provides protection to the oscilloscope front panel and also provides a convenient, protected storage space for the accessories group. Use of spring-loaded latches allows the cover to be easily detached for access to both the front panel and the accessories, which are protected and secured by a hinged panel inside the cover. The accessories group consists of an assortment of probes, coaxial cables, adapter, and connectors.

b. *Operation*. The following paragraphs provide information necessary to the operation of the oscilloscope. The oscilloscope features a combination of display functions for a wide range of signal measurement applications. The major functions consist of five main frame and four time base generator modes. These modes are defined as follows:

(1) *Main Frame Modes*.

(a) *Left*. Selects signal. applied to left vertical plug-in channel for crt display.

(b) *Alternate*. Selects signals alternately from left and right vertical plug-in channels for display on the crt. Channel switching occurs at the end of each sweep signal from the dual time base.

(c) *Chop*. Selects signals alternately from the left and right vertical plug-in channels for display. Channel switching occurs at. 1-megahertz rate from an internal clock generator.

(d) *Add*. Adds, algebraically, signals from the left and right vertical plug-in channels. This is useful. for removing undesired components common to both signals (common mode rejection) or to add signal component to one channel to offset a like component in the, other channel (dc offset).

(e) *Right*. Selects the signal applied to the right vertical plug-in channel for crt display.

(2) *Time Base Generator Modes*.

(a) *Main Sweep*. Provides a means of displaying the signal in direct time relationship using any main frame mode discussed in paragraphs 2b(1)(a) through 2b(1)(e) above.

(b) *Delayed Sweep*. Provides a means of displaying the signal in delayed time relationship in any main frame mode listed in paragraphs 2b(1)(a) through 2b(1)(e). Displayed sweep is delayed by the main sweep and DELAY TIME MULT control settings.

(c) *Single Sweep*. Allows the time base generators to run through one sweep cycle only. Another sweep cannot be triggered until the RESET switch is pressed. Can be used with any main frame mode listed in paragraphs 2b(1)(a) through 2b(1)(e).

(d) *Amplifier*. Provides a means of applying the external signal to the horizontal amplifier. Can be used with x-y measurements, or for applying an external sweep signal.

c. *Controls and Indicators*. All controls, indicators, protective devices, and connectors for both the front and rear panels of the oscilloscope are described (in the following paragraphs) as to section of the scope and the function performed.

(1) *Front Panel* (figure 97 on the following page).

(a) *INTENSITY Control*. Controls the brightness of the display. inoperative when the horizontal plug-in compartment is empty.

(b) *FOCUS Potentiometer*. Controls the definition of the display.

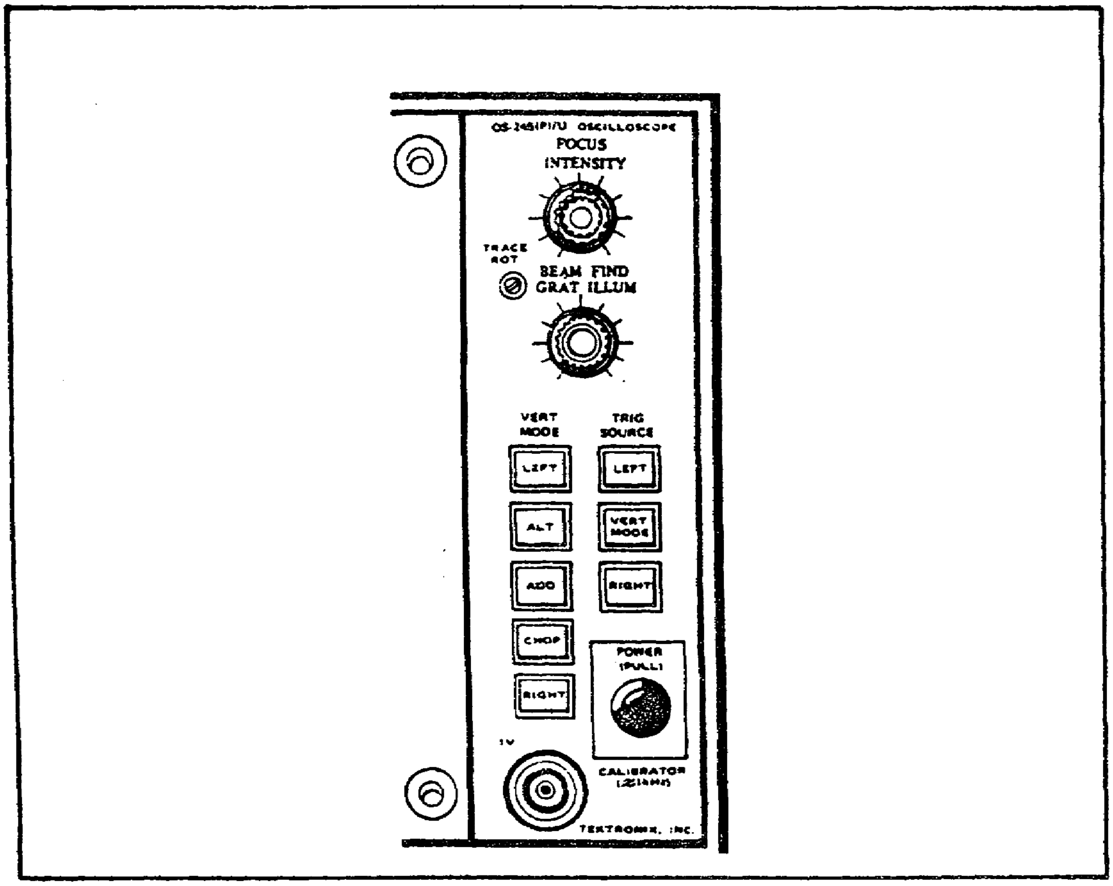


FIGURE 97. MAIN FRAME CONTROLS.

(c) *TRACE ROTATION Potentiometer*. Controls the alignment of trace with horizontal graticule lines.

(d) *GRAT ILLUM Potentiometer*. Controls the brightness of the graticule lines.

(e) *BEAM FINDER Switch*. A spring-loaded switch. When pressed, causes the display to be compressed to within the graticule area, independent of control settings or applied signals.

(f) *VERTICAL MODE Switches*. Alternate-action switches.

1 *LEFT*. Selects signal from the left hand vertical amplifier.

2 *ALT*. Selects signals from the left-band and right-hand vertical amplifiers in alternating patterns for display. Signals are switched after each sweep.

3 *ADD*. Selects signals from both vertical amplifiers for display. Signals are algebraically added and sums displayed.

4 *RIGHT*. Selects signal from the right-hand vertical amplifier.

(g) *TRIG SOURCE Switches*. Alternate-action switches.

1 *LEFT*. Selects trigger signal from left-hand vertical amplifier.

2 *VERT MODE*. Trigger signal automatically follows vertical displays except when chopped vertical mode is selected. In the chopped mode, the trigger occurs at 1-megahertz rate under control of internal oscillator.

3 *RIGHT*. Selects trigger signal from right-hand vertical amplifier.

(h) *POWER Switch*. Push-pull switch. Controls power to the oscilloscope.

(i) *CALIBRATOR Connector*. Provides a connecting cable for the calibrator output signal.

(2) *VERTICAL AMPLIFIERS*. Two are shown in figure 98 on the following page.

(a) *POSITION Control*. Controls the vertical position of the trace.

(b) *POLARITY Switch*. Provides for display inversion. In the +UP position, positive-going input signal causes upward trace deflection; in the INVERT position, positive going input signal causes downward trace deflection.

(c) *MAG Switch*. Provides for decreasing deflection factor. In the x1 position, the deflection factor is selected by the VOLTS/DIV switch and the VARIABLE potentiometer; in the x10 REDUCED BANDWIDTH position, the deflection factor is 1/10 that selected by the VOLTS/DIVE switch and the VARIABLE potentiometer.

(d) *GAIN Potentiometer*. Controls the deflection factor fine calibration.

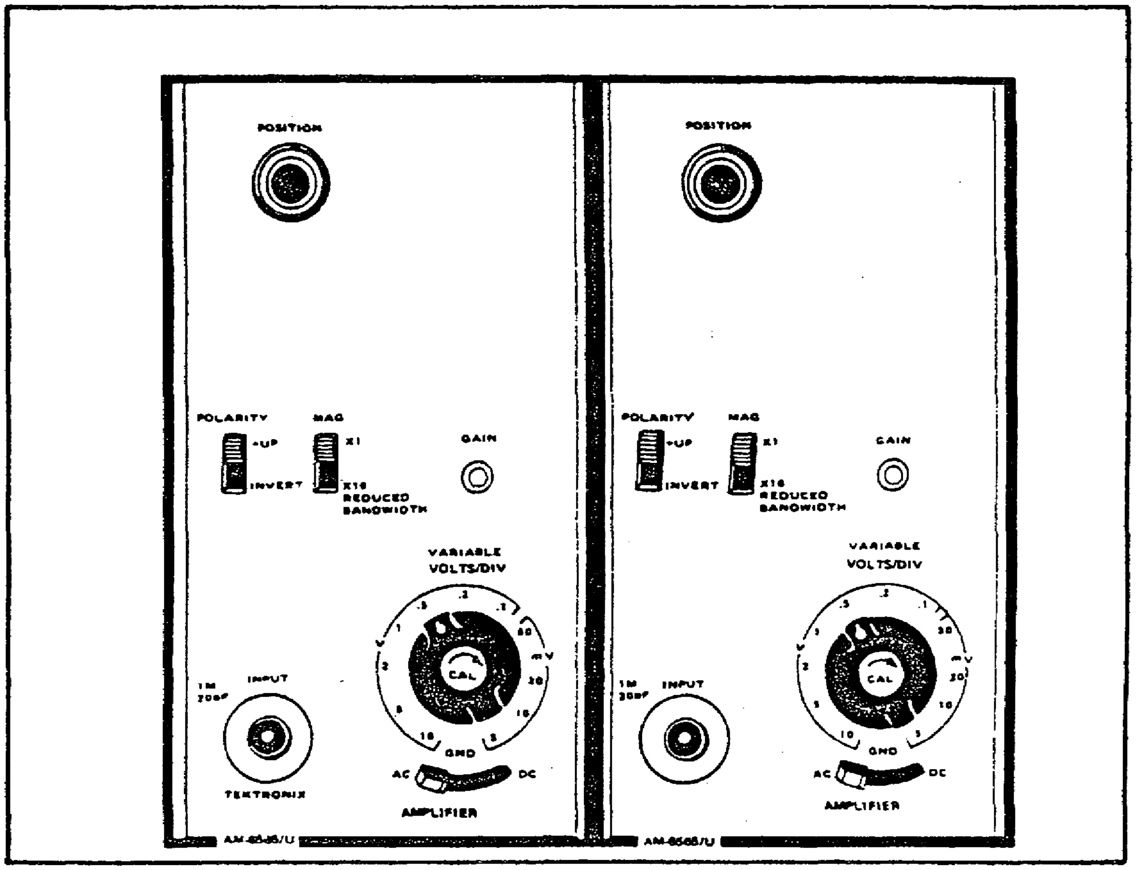


FIGURE 98. VERTICAL AMPLIFIER CONTROLS.

(e) *Input Connector*. Provides for connecting the amplifier input signal cable.

(f) *VOLTS/DIV Switch*. Provides for selecting the calibrated deflection factors From 5 millivolts per division to 10 volts per division in 11 steps, in 1, 2, 5, ... sequence.

(g) *VARIABLE Potentiometer Switch*. Provides for continuously variable uncalibrated settings (up to 2.5 times) between the calibrated deflection factor steps. Extends the range to 25 volts per division or more.

(h) *AC/GND/DC Switch*. Provides for selecting the input coupling mode. In the AC position, the input signal is capacitively coupled to the amplifier input with the dc component blocked. In the GND position, the amplifier input is grounded while maintaining the same input signal load (provides the charge path for the ac coupling capacitor to precharge the input circuit before switching to ac). In the DC position, all components of the input signal are coupled to the amplifier input.

(3) *DUAL TIME BASE Front Panel* (figure 99).

(a) *LEVEL Potentiometer.* Provides for selection of the amplitude point, on the trigger signal at which triggering occurs.

(b) *SLOPE Switch.* Provides for selection of either the positive- or negative-going slope of the trigger signal on which to trigger.

(c) *TRIG'D Indicator.* Lights to indicate that the main sweep is triggered and will produce a display with the correct setting of the INTENSITY and POSITION controls.

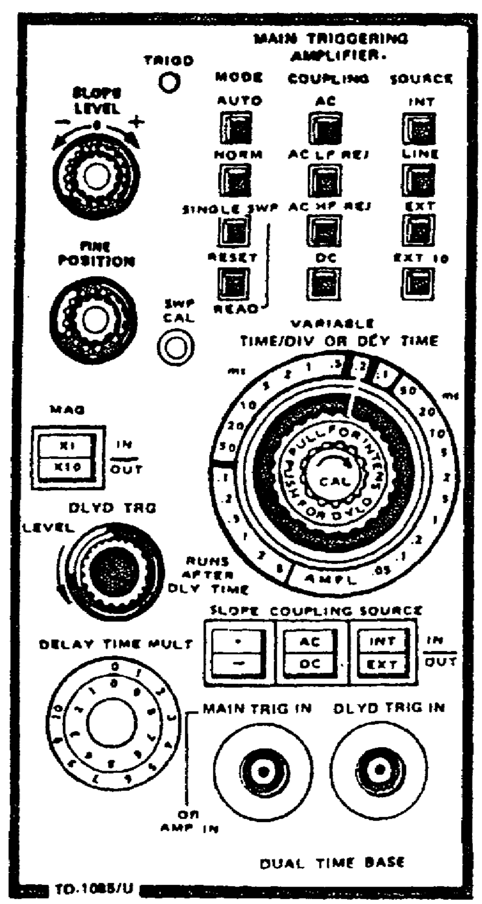


FIGURE 99. DUAL TIME BASE CONTROLS.

(d) *MAIN TRIGGERING Switches*. Alternate-action switches/indicators.

1 *MODE Switches*. Provides for the selection of the main triggering mode and indicates the selection.

a *AUTO*. When pressed, the sweep is initiated by the applied trigger signal at the point selected by the LEVEL and SLOPE controls, if the trigger signal repetition rate is above 30 Hertz and within the range selected by the COUPLING switch. The triggered sweep can be obtained only over the amplitude range of the applied trigger signal. When the LEVEL, control] is set outside the amplitude range, the [.rigger repetition rate is outside the frequency range selected by the COUPLING switch, or the trigger signal is inadequate, and no trace is displayed.

b *NORM*. When pressed, the sweep is initiated by the amplified trigger signal at the point selected by the LEVEL, and SLOPE controls over the frequency range selected by the COUPLING switch. When the LEVEL control is set outside the amplitude range, the trigger repetition rate is outside the frequency range selected by the COUPLING switch, or the trigger signal is inadequate, and no trace is displayed.

c *SINGLE SWP*. When pressed, further sweeps cannot be displayed after one sweep until the RESET switch is pressed. The display is triggered as for NORM operation using the main triggering controls.

d *RESET-READY*. When pressed while in the single sweep mode, one sweep is displayed at the next occurrence of the trigger pulse (if triggering settings are correct). The indicator lights and remains lighted until the trigger is received, indicating that the unit is reset. After trigger receipt and sweep display, the indicator extinguishes.

2 *AMPLIFIER COUPLING Switches*. Provides for the selection of the main triggering coupling.

a *AC*. When pressed, the dc components of the signals are rejected and ac signals below approximately 30 Hertz are attenuated. AC signals

between 30 Hertz and 50 megahertz are accepted intact.

b *AC LF REJ*. When pressed, the dc components of the signals are rejected and ac signals below approximately 30 kilohertz are attenuated. AC signals between 30 kilohertz and 50 megahertz are accepted intact.

c *AC HF REJ*. When pressed, the dc components and signals below 30 Hertz and above 50 kilohertz are attenuated. Signals within the range of 30 Hertz to 50 kilohertz are accepted intact.

d *DC*. When pressed, all signals from dc to 50 megahertz are accepted.

3 *AMPLIFIER SOURCE Switches*. Prvides for the selection of the main trigger source and indicates the selection.

a *INT*. When pressed, the trigger signal is obtained from the associated vertical amplifier.

b *LINE*. When pressed, the trigger signal is obtained from a sample o the oscilloscope input power frequency.

c *EXT*. When pressed., the trigger signal is obtained from the external source through the MAIN TRIG IN connector.

d *EXT 10*. Same as the EXT, except that the trigger signal is attenuated to approximately 10 percent of the input amplitude.

(e) *POSITION Potentiometer*. Provides for the coarse adjustment of the horizontal position of the trace.

(f) *FIND Potentiometer*. Provides for the find adjustment of the horizontal position of the trace.

(g) *SWP CAL Potentiometer*. Provides for adjustment to the main gain of the dual time base to the main frame for calibrated sweep rates.

(h) *MAG Switch*. Provides for the selection of horizontal magnification. X1 (IN) selects the unmagnified sweep at the basic rate indicated by the TIME/DIV switch setting; X10 (OUT) increases the sweep rate of the main and delayed sweep generator by horizontally expanding the center centimeter of the display 10 times.

(i) *TIME*/DIV OR DLY TIME Switch. Provides for the selection of the basic sweep rate of the main sweep generator, for operation of the main sweep display mode and the selection of the delay time (to be multiplied by the DELAY TIME MULT 10-turn dial setting) for operation in the intensified or delayed sweep display modes. The MAG switch must be in the X1 position (IN) and the VARIABLE potentiometer/switch must be in the CAL position for the indicated sweep rate.

(j) *Delayed Time/Division Switch, Intensify Switch*. Selects the sweep rate of the delayed sweep generator for operation in the delayed sweep and intensified display modes. The VARIABLE control must be in the extreme clockwise or CAL position and the MAG switch must be in the XI position (IN) for the indicated sweep rate.

NOTE

The interrelationships between the TIME/DIV OR DLY switch, the delayed lime/division switch, and the intensify switch is complex. For full and efficient use of these functions, the following determinations of the display modes must be understood:

<u>1</u> *MAIN SWEEP*. In the main sweep mode, the time base switches are locked together and the time per division (sweep rate) is bracketed by the black lines on the TIME/DIV OR DLY TIME switch. Only the main time base (sweep) generator operates in this mode.

<u>2</u> *INTENSIFIED SWEEP*. In the intensified sweep mode, both time base generators are used, but only the main sweep is displayed. The delayed sweep generator unblanking signal is used to intensify (brighten) the main sweep display when the delayed sweep generator runs. The main Lime base sweep rate is bracketed by the black lines on the TIME/DIV OR DLY TIME switch. The delayed time base sweep rate is selected by pulling the delayed time/division switch out and turning it clockwise. With the switch pulled out, an intensified zone

appears on the main sweep. The start of the intensified zone is determined by the DELAY TIME, MULT dial setting. The duration of the intensified zone is determined by the delayed time/division switch setting. The purpose of the intensified sweep mode is to locate the portion of the trace that is to be displayed in the displayed sweep mode.

3 *DELAYED SWEEP*. In the delayed sweep mode, the delayed time/division switch is pushed in and the part of the display shown in the intensified zone discussed previously is then displayed on the delayed sweep and expanded over the full 10-centimeter horizontal scale. The magnitude of expansion from the intensified to the delayed mode is the ratio of the main sweep to the delayed sweep time per division setting. The delay time from the start of the main sweep to the start of the delayed sweep is found by multiplying the main sweep time per division by the DELAY TIME MULT dial setting. The delayed sweep mode enables the operator to select any part of the main sweep display and expand that part for more careful analysis, and to make precise time difference measurements.

(k) *VARIABLE Potentiometer/Switch*. Provides for uncalibrated, continuously variable deflection factors between the calibrated settings of t he TIME/DIV OR DLY TIME switch. The uncalibrated deflection factor range is extended to at least 12.5 seconds per division. When the control is set to the extreme clockwise position, the switch is operated to select the calibrated deflection factors.

(1) *DLY'D TRIG Potentiometer/Switch*. Selects the mode and level. for delayed triggering. When the control is in the extreme clockwise (RUNS AFTER DLY TIME) position, the delayed sweep runs immediately following delay time selection by the TIME/DIV OR DLY TIME switch, and the DELAY TIME MULT 10-turn dial potentiometer. Delayed SLOPE, COUPLING, and SOURCE switches are not activated.

When the control is turned counterclockwise from the switch detent, the delayed sweep is triggerable. The LEVEL potentiometer then selects the point on the trigger signal at which the delayed sweep is triggered and the delayed SLOPE, COUPLING, and SOURCE switches are activated.

(m) *SLOPE Switch*. An alternate-action switch that provides for selecting a portion of the trigger signal to start the delayed sweep. The (IN) position provides that the delayed sweep is triggered from the positive-going portion of the trigger signal. The (OUT) position provides that the delayed sweep is triggered from the negative-going portion of the trigger signal.

(n) *COUPLING Switch*. An alternate-action switch that provides for the selection of the method of coupling the trigger signal to the delayed trigger circuits. The ac (IN) position provides that the dc components are rejected and ac signals below approximately 30 Hertz are attenuated; signals between 30 Hertz and 50 megahertz are accepted intact. The dc (OUT) position provides that all signals from the dc to 50 megahertz are accepted intact.

(o) *SOURCE Switch*. An alternate-action switch that provides for the selection of the source of the delayed trigger signal determining the function of DLY'D TRIG IN connector. The INT (IN) position provides that the delayed trigger signal is obtained from the external source through the DLY'D TRIG IN connector.

(p) *DELAY TIME MULT 10-Turn Dial Potentiometer*. Provides for selecting the variable sweep delay between 0 and 10.0 times the delay indicated by the TIME/DIV or DLY TIME switch setting.

(q) *MAIN TRIG IN OR AMP IN*. Provides for the connection of the connecting cable to the dual time base for external triggering signal input. When the MAIN TRIGGERING AMPLIFIER SOURCE EXT or EXT 10 switch is pressed and the TIME/DIV 0R DELAYED TIME switch is set to any other position than AMPL, the connector provides for external trigger input to the main triggering circuits. When the MAIN TRIGGERING AMPLIFIER SOURCE EXT or EXT 10 switch is pressed and the TIME/DIV OR DLY'D TIME switch is set to AMPL, the connector provides for external horizontal input.

(r) *DLY'D/TRIG IN Connector*. Provides the connection point for connecting the cable to the dual time base for external delayed triggering signal input.

(4) *Oscilloscope Rear Panel*.

(a) *LINE FUSES*. Provides overload protection to the oscilloscope circuits.

(b) *MAIN SWP OUTPUT Connector*. Provides the connecting point for connecting the cable to the monitor main sweep output signal.

(c) *DELAYED SWP OUTPUT Connector*. Provides the connecting point for connecting the cable to the monitor delayed sweep output signal.

(d) *EXT Z AXIS Connector*. Provides the connecting point for connecting the cable to supply the external intensification control signal.

(e) *MAIN SWP GATE OUTPUT Connector*. Provides the connecting point for connecting the cable to the monitor main sweep gate output signal.

(f) *DELAYED SWP GATE OUTPUT Connector*. Provides the connecting point for connecting the cable to the monitor delayed sweep gate output signal.

(g) *DELAYED TRIG OUTPUT Connector*. Provides the connecting point for the cable to the monitor delayed trigger output signal.

(h) *Power Input Connector and Cable*. Provides for the connection of the external power cable to the oscilloscope.

d. Operation. The paragraphs that follow contain the procedures and general information required to operate the AN/USM-281C oscilloscope. Included in this discussion are the turn-on procedures, operating procedures, and the turn-off procedures. Note that it is not necessary that all three plug-in compartments be filled in order to operate the oscilloscope. However, at environmental extremes, electromagnet interference may be radiated into or out of the oscilloscope through an empty compartment. If a plug-in unit is not available, it may be necessary to cover an empty compartment with a blank panel.

(1) *Turn-On Procedures*. Prepare the oscilloscope for operation as follows:

(a) *Main Frame Controls*. Set the main frame controls as follows:

Turn the INTENSITY potentiometer to the fully counterclockwise position. Then adjust the FOCUS potentiometer to the midrange setting. Ensure that the BEAM FINDER switch is NOT pressed. Now adjust the GRATICULE ILLUM potentiometer as desired. Finally, ensure that the LEFT VERT MODE switch is depressed and that the VERT MODE TRIG SOURCE switch is depressed.

Once the main frame controls are set according to the above procedures, set the vertical amplifier controls.

(b) *Vertical Amplifier Controls*. Set the vertical amplifier front panel controls as follows:

Turn the POSITION potentiometer to the midrange position. Then place the POLARITY switch in the +UP position. With the POLARITY switch in the +UP position, place the MAG switch to the X1 position. Place the VOLTS/DIV switch to the 2V position and turn the VARIABLE potentiometer/switch fully clockwise into the switch detent. Finally, place the AC/GND/DC switch to the AC position.

Now that the vertical amplifier controls have been properly positioned, set the dual time base controls.

(c) *Dual Time Base Controls*. Set the dual time base controls as follows:

Move the LEVEL potentiometer to the midrange position and the SLOPE indicator to the "+" position. Set the MODE switch to AUTO, the COUPLING switch to AC, and the SOURCE switch to INT'. Turn the POSITION and FINE potentiometers to the midrange position. Press the XI MAC switch. Then set the TIME/DIV OR DLY TIME switch to the 1 ms position and the delayed time/division switch also to the 1 ms position. Turn the VARIABLE potentiometer/switch clockwise to the switch detent. Turn the DLY'D TRIG potentiometer/switch fully clockwise to the RUNS AFTER DLY TIME position. Ensure that. the "+" SLOPE pushbutton switch is pressed in, the AC COUPLING pushbutton switch is pressed in, and the INT SOURCE pushbutton is pressed in. Finally, set the DELAY TIME MULT potentiometer to the 1.00 position.

After all the controls are properly set, connect the oscilloscope to a power source of the proper voltage and frequency. Pull the POWER switch knob out to the switch stop to apply power. Finally, allow the oscilloscope to warm up for 5 minutes or wore.

(2) *Simplified Operating Procedures*. The following procedure is provided to aid in quickly setting the oscilloscope controls to present a display.

(a) *Single-Trace Display*. The following procedure will produce a display of the input signal of one vertical amplifier on one trace of the dual time base. In this case, the left-hand vertical amplifier is used. The right-hand vertical amplifier can be used by making the appropriate modifications to the procedure.

Set the controls according to the procedures contained in paragraphs 2d(l)(a) through 2l(11) '(c), beginning on the previous page. Connect the input signal to the INPUT connector on the left-hand vertical amplifier. Then turn the INTENSITY potentiometer clockwise until the display is visible. If no display is visible by the midrange position, perform the following steps:

Step 1. Press and hold the BEAM FINDER switch.

Step 2. Set the VOLTS/DIV switch on the vertical amplifier for the display that remains within the vertical area of the graticule.

Step 3. Adjust the POSITION potentiometer on the vertical amplifier for the desired vertical position of the display.

Step 4. Adjust the POSITION potentiometer on the dual time base for the desired horizontal position of the display.

Step 5. Release the BEAM FINDER switch.

Step 6. If necessary, adjust the LEVEL potentiometer on the dual time base for a stable display.

Step 7. Adjust the FOCUS potentiometer for a well-defined display.

Once the above steps have been performed (if required), set the TIME/DIV OR DLY TIME switch on the dual time base for the display of desired number of cycles of the input signal.

(b) *Dual-Trace Display*. The following procedure will produce a display of the input signals of two vertical amplifiers on two traces by the dual time base.

Perform the turn-on procedures that were contained in paragraph (s) 2d(1)(a) through 2d(1)(c)(pages 148 and 149). Once these procedures have been performed, connect the input signal to the INPUT connector on each vertical amplifier. Turn the INTENSITY potentiometer clockwise until the display is visible. If no display is visible by the midrange position on the INTENSITY potentiometer, perform the following steps:

Step 1. Press and hold the BEAM FINDER switch.

Step 2. Set the VOLTS/DIV switch on the left-hand vertical amplifier for the display that remains within the vertical area of the graticule.

Step 3. Adjust the POSITION potentiometer on the left-hand vertical amplifier for the desired vertical position of the display.

Step 4. Adjust the POSITION potentiometer on the dual time base for the desired horizontal position of the display.

Step 5. Release the BEAM FINDER switch.

Step 6. If necessary, adjust the LEVEL potentiometer on the dual time base for a stable display.

Step 7. Adjust the FOCUS potentiometer for a well-defined display.

After these steps have been performed (if' required), set the VOLTS/DIV switch on the left-hand vertical amplifier for a display approximately four centimeters in amplitude. Adjust the POSITION potentiometer on the left-hand vertical amplifier to place the display in the upper half of the graticule area. Press the VERT MODE RIGHT switch. Set the VOLTS/DIV switch on the right-hand vertical amplifier for a display approximately four

centimeters in amplitude. If the display of the second trace is not visible, adjust the POSITION potentiometer on the right-hand vertical amplifier to place the display in the lower half of the graticule area. Then press the VERT MODE ALT switch in. The dual trace display should appear on the crt. Note that the VERT MODE CHOP switch would produce a somewhat similar display. Finally, set the TIME/DIV OR DLY TIME switch on the dual time base for a display of the desired number of cycles of the input signal.

(c) *Delayed Sweep-Single Trace Display*. The following procedures will produce a delayed sweep display of the input signal to one vertical amplifier on one trace by the dual time base.

Perform the complete single-trace display procedure as outlined in paragraph 2d(2)(a) on page 150, with the exception of setting the TIME/DIVE OR DLY TIME switch on the dual time base for a display of the desired number of cycles of the input signal. Instead, set the TIME/DIV OR DLY TIME switch so that the portion of the sweep to be magnified is near the center of the graticule area. Now pull the delayed time/division switch out to the stop and turn it clockwise to a higher rate setting (to perhaps the second or third position; this will be adjusted later). One portion of the trace should be displayed at a higher intensity level. If necessary, adjust the INTENSITY potentiometer for the desired viewing level. Now adjust the DELAY TIME MULT dial potentiometer to move the intensified portion of the trace to cover the portion of the display to be examined. Then adjust the settings of the TIME/DIV OR DLY TIME switch, and the delayed time/division switch, for desired sweep rates for the main and delayed sweeps. Finally, push the delayed time/division switch in. The section of the trace that was previously intensified (delayed sweep) should be expanded to cover the entire graticule horizontal scale.

If the waveform segment to be examined is not steady, it may be necessary to turn the DLY'D TRIG potentiometer counterclockwise (out of the switch detent) to allow the delayed sweep triggering on some portion of the signal to be examined. In that case, the point on the signal at which the triggering occurs is selectable by the position of the DLY'D TRIG potentiometer.

(d) *Delayed Sweep-Dual-Trace Display*. The following procedure will produce a delayed sweep display of the input signals to the two vertical amplifiers on the two traces by the dual time base.

Perform the complete dual-trace procedure as outlined in paragraph 2d(2)(b) on page 151, except for the following procedures. Do not press the VERT MODE ALT switch in or set the TIME/DIV OR DLY TIME switch on the dual time base for a display of the desired number of cycles of the input signal.

After the procedures have been performed, press either the VERT MODE CHOP or the VERT MODE ALT switch in (depending upon the desired mode of the vertical input switching). Input signals to both vertical amplifiers should be displayed on the delayed sweeps.

(e) *X-Y Display*. The following procedure will produce a display of one signal versus another, rather than against time.

Begin this procedure by first removing the dual time base unit from the right-hand compartment. Then remove the vertical amplifier from the center compartment and re-install in the right-hand compartment. Now set all the controls in paragraphs 2(d(1)(a) and 2d(1)(b) on page 149). Connect the x input signal to the left-hand vertical amplifier and the y input signal to the right-hand vertical amplifier. Now turn the INTENSITY potentiometer clockwise until the display is visible. If no display is visible by the midrange position on the INTENSITY potentiometer, perform the following steps:

Step 1. Press find hold the BEAM FINDER switch.

Step 2. Set the VOLTS/DIV switch on each vertical amplifier for the display that remains within the vertical and horizontal area of the graticule.

Step 3. Adjust the POSITION potentiometer on each vertical amplifier for the desired vertical position of the display.

Step 4. Release the BEAM FINDER switch.

Step 5. Adjust the FOCUS potentiometer for a well-defined display.

The above procedures, paragraphs 2a(1) through 2d(2)(e), present a general view of the AN/USM 281C oscilloscope, it's controls and indicators, and the basic operating procedures. For more detailed information, refer to TM 11-6625-2658-14.

3. Conclusion

In the three tasks which form this lesson, information concerning electronic principals was discussed. Task one dealt with magnet ism, analysis of inductive and capacitive circuits, and the production of alternating current. Task two dealt with the basic fundamentals of semiconductors, including PNP and NPN transistors. In the third task, the AN/USM-281C oscilloscope, including its setup, operation, and use was presented.

On the following page is a practical exercise designed to test your retention of the information presented in this subcourse. When you feel you have a firm understanding of the information presented, turn the page and answer the questions.

PRACTICAL EXERCISE 1

1. Instructions

Below are some questions concerning the information that was presented in this subcourse. On a separate sheet of paper, answer theses questions using your knowledge of electronic principles and this subcourse.

2. Requirement

a. What are magnetic materials?

b. What characteristics do all ferromagnetic materials have in common?

c. How does the law of magnetic poles relate to the law of electric charges?

d. What is the difference between the domain theory and Weber's theory of magnetism?

e. What is a magnetic line of force?

f. An electromotive force (emf) is generated in a conductor when the conductor is cut by what type of field?

g. Define inductance.

h. List the five factors that affect the inductance of a coil.

i. Define the terms "capacitor" and "capacitance."

j. State the four characteristics of electrostatic lines of force.

k. An electron moves into the electrostatic field between a positive charge and a negative charge. Toward which charge will the electron move?

l. State three factors that affect, the capacitance of a capacitor.

m. Define direct current and alternating current.

n. What is a disadvantage of a direct-current system with respect to supply voltage?

o. What kind of electrical current is used in most modern power distribution systems?

p. What is the shape of a magnetic field that exists around (a) a straight conductor and (b) a coil?

q. Define frequency.

r. What do the period and the wavelength of a sine wave measure, respectively?

s. What is a solid-state device?

t. Name the two types of current flow in a semiconductor.

u. Name three of the commonly used manufacturing techniques used in PN junction construction.

v. Briefly describe the AN/USM-281C oscilloscope.

w. Name the four units of the AN/USM-281C oscilloscope.

LESSON 1. PRACTICAL EXERCISE -- ANSWERS

Requirement

a. Those materials that are attracted by magnets and have the ability to become magnetized.

b. The relative ease with which they are magnetized.

c. They are very similar; like charges repel, unlike charges attract-like poles repel, unlike poles attract.

d. The domain theory is based upon the electron spin principle; Weber's theory uses the concept of tiny molecular magnets.

e. An imaginary line used to illustrate magnetic effects.

f. Magnetic field.

g. Inductance is the property of a coil (or circuit) which opposes any CHANGE in current.

h. The number of turns in a coil.
The type of material used in the core.
The diameter of the coil.
The coil length.
The number of layers of windings in the coil.

i. A capacitor is a device that stores electrical energy in an electrostatic field.

Capacitance is the property of a circuit which opposes changes in voltage.

j. They are polarized from positive to negative.

They radiate from a charged particle in straight lines and do not form closed loops.

They have the ability to pass through any known material.

They have the ability to distort the orbits of electrons circling the nucleus.

k. Toward the positive charge.

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l. The area of the plates.

The distance between the plates.

The dielectric constant of the material between the plates.

m. Direct current is an electrical current which flows in only one direction.

Alternating current is an electrical current which is constantly varying in amplitude, and which changes direction at regular intervals.

n. The dc voltage must be generated at the level required by the load.

o. Alternating current

p. (a) The field consists of concentric circles in a plane perpendicular to the wire (b) the field of each turn of wire links with the fields of adjacent turns producing a two-pole field similar in shape to that of a simple bar magnet.

q. Frequency is the number of complete cycles of alternating voltage or current completed each second.

r. The period measures time and the wavelength measures distance.

s. An electronic device which operates by virtue of the movement of electrons within a solid piece of semiconductor material.

t. Electron flow and hole flow

u. Grown, Fused Alloy, and Point-Contact

v. The AN/USM-281C oscilloscope is a light-weight, solid-state instrument designed for the general purpose of waveform measurements using single- or dual-trace displays with normal or delayed sweep.

w. The four units of the AN/USM-281C oscilloscope are the main frame, vertical amplifier, dual time base, and the cover.