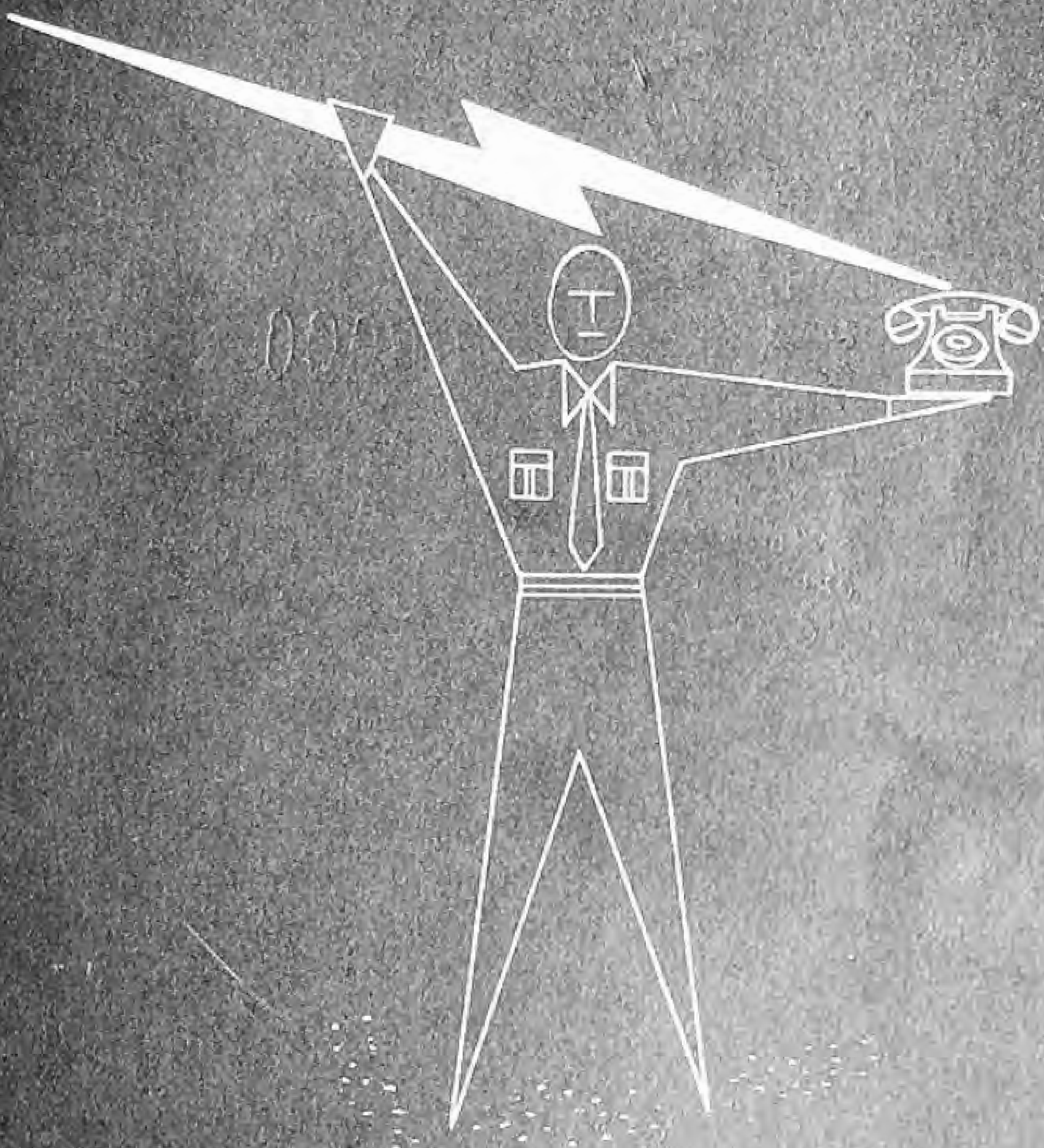
Electricity

FOR THE TELEPHONE MAN



AMERICAN TELEPHONE AND TELEGRAPH COMPANY AND MICHIGAN BELL TELEPHONE COMPANY

ELECTRICITY

for the

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PREFACE

This textbook sets down the principles of magnetism and electricity upon which all electrical communication is based. It is intended to serve as a primer of technical training for the telephone craftsman.

The comprehension of even the most intricate electrical circuits depends upon a familiarity with the fundamental ideas of electricity. If these fundamentals are properly understood, the more advanced concepts will not be difficult to learn. To this end the early theory of current flow, in which current was considered to flow from positive to negative, has been abandoned. Instead, this book is based on the electron theory which holds that an electric current is a flow of electrons from negative to positive. In tracing elementary telephone circuits the choice of theory is of little consequence. However, the rapid inclusion of electronic devices into all phases of telephone plant suggests the desirability of employing the electron theory from the beginning.

Illustrations have been used extensively throughout the book. In addition to simplifying the explanations, the reader will develop an aquaintance with the proper symbols and schematic conventions of telephone circuitry.

Questions are included at the end of each chapter to stimulate more thorough study and to allow the reader to test his knowledge.

Material for this book has been gathered from innumerable Bell System sources; notably from publications of the Michigan Bell Telephone Company and the Illinois Bell Telephone Company.

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CHAPTER I

THE ELECTRON THEORY

1. COMPOSITION OF MATTER

1.01 The basic principles of electricity are readily understood by utilizing the electron theory. The air a person breathes, the water he drinks, the bus in which he rides, his own body, all constitute matter. Matter is any substance having weight and occupying space.

1.02 All matter is made up of one or more fundamental substances, such as oxygen, hydrogen, iron, carbon and copper, known as elements because they can not be broken into simpler substances by chemical processes.

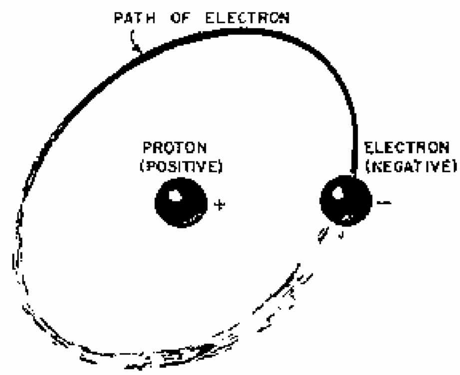
1.03 Matter appears in three forms: It may be a pure elemental substance; it may be a compound formed by the chemical union of two or more elements; or it may be a mixture of several elements or compounds which are not bound together by chemical action.

1.04 Regardless of the form in which it is found all matter may be broken down into molecules. The molecule of a compound always contains two or more atoms, while the molecules of some elements consist of a single atom.

2. COMPOSITION OF ATOM

2.01 An atom is the smallest particle of an element which retains all the characteristics of the element. Although it is an extremely small particle of matter, the atom can be divided into a positively charged nucleus or core and a cloud of negatively charged particles called electrons that revolve at a very high speed around the nucleus.

2.02 Figure 1-1 shows the atomic structure of the simplest atom, the hydrogen atom, which contains one electron revolving around the proton which acts as the nucleus. The positive charge of the proton exactly equals the negative charge of the electron so that the atom is electrically neutral.



HYDROGEN ATOM

FIG. 1-1

2.03 In Figure 1-2 the nucleus of the helium atom contains two protons. The resulting positive charge is just sufficient to hold two revolving electrons in orbits around the nucleus and the net charge of the atom is zero.

HELIUM ATOM

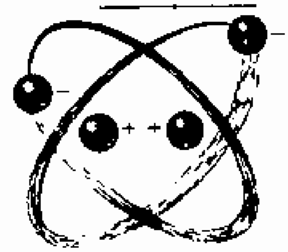


FIG. 1-2

2.04 Atoms of the other elements are more complex than the two simple examples shown here. However, the only difference among the atoms of the various elements lies in the number and arrangement of the protons and electrons of which each atom is composed.

2.05 All atoms are electrically neutral since the number of positive charges always equals the number of negative charges.

2.06 Since all matter is composed of atoms, and all atoms are composed of positive and negative electrical charges, all matter is electrical in nature.

3. CONDUCTORS AND INSULATORS

3.01 In any material some of the electrons are not tightly held in their orbits. Such electrons, called free electrons, are able to move from one atom to another with relative ease. If a voltage is impressed across a substance, the free electrons are very quickly set in motion, causing the flow of an electric current. Materials that allow an easy flow of free electrons are called conductors.

3.02 In many materials such as glass, hard rubber, and porcelain, there are very few free electrons. These materials are known as insulators because it is difficult to force an electric current through them.

4. QUANTITY OF ELECTRICITY

4.01 In most electrical devices, we are concerned with a very great number of electrons. For convenience in dealing with these large quantities, a unit of electrical quantity has been established. This unit is the coulomb and is equal to 6,281,000,000,000,000,000 electrons.

4.02 The exact number of electrons is of no importance. The thing to remember is that the standard unit of quantity of electricity is the coulomb.

5. CURRENT FLOW

5.01 The free electrons in a conductor are moving constantly and changing their positions in a haphazard manner. When an electric force (potential) is connected to the two ends of a copper wire, the random motion of the free electrons is directed toward the positive terminal by the attraction of the positive potential and away from the negative terminal by the repulsion of the negative potential. Although the free electrons themselves do not move through the wire at a high speed, the disturbances that cause them to drift along the wire move with speeds approaching the speed of light.

5.02 The electric force forces the free electrons to drift from atom to atom along the wire as long as it is connected. When it is removed, each atom is left with its proper number of electrons since those that were taken from the wire at the positive terminal of the battery exactly equals those that were added at the negative terminal. This drift or flow of free electrons along a wire is called an electric current. It was common use in older text books to consider electric current flow was from positive to negative. At present the accepted theory is electric current flow is from negative to positive. (Electron Theory)

Because of its importance in the explanation of vacuum tube functions, any reference in this book to current flow is based on the electron theory.

5.03 The rate of flow of electrons is measured in units called amperes. One ampere flows when one coulomb passes a point in one second. In other words, amperes are coulombs per second. We say then that the ampere is the unit of electric current.

6. ELECTROMOTIVE FORCE

6.01 The force that causes electrons to flow in an electric circuit is called the electron moving force or electromotive force. This is sometimes abbreviated to E.M.F.

6.02 The measure of an electromotive force is its potential. When two points differ in electrical pressure, a potential difference is said to exist between them.

6.03 The unit of potential difference is the volt. One volt is a potential difference such that a certain amount of work is required to take one coulomb across it. The amount of work is the joule and will be described in the chapter on power in D.C. circuits.

6.04 The terms electromotive force and potential difference are often used interchangeably. There is a technical distinction, however, in that an electromotive force is established by a battery, generator or other primary source of electrical energy, while a potential difference exists between two points in an electrical circuit through which current is flowing.

7. RESISTANCE

7.01 Since an electric current is a flow of free electrons in a material, those substances which have a large number of free electrons are able to pass a larger current with a given electric force than can a substance with few free electrons. The number of free electrons in a material determines its resistance to flow of electric current. The resistance of a material is proportional to its length and inversely proportional to its cross-sectional area. A unit in which resistance is deliberately lumped is known as a resistor. A resistor dissipates energy because some of the free electrons which are set in motion by the electric force collide with others and generate heat.

7.02 As the temperature of a pure metal wire resistor is increased, the random motion of the free electrons is increased and more collisions take place so that there are effectively fewer electrons able to flow as a current. Therefore, the resistance of a pure metal increases as the temperature is raised.

7.03 The resistance of an electrical circuit is measured in units called ohms. One ohm of resistance is that through which one ampere of current will flow when an electromotive force of one volt is applied.

8. QUESTIONS

1. What is matter?
2. What is an element?
3. What is the smallest part an element can be broken down into?
4. What two charges make up an atom?
5. Is an atom electrically neutral?
6. What is the difference between atoms of different elements?
7. Is all matter electrical in nature?
8. What is a free electron?
9. Does an insulator have many free electrons?
10. What happens to the free electrons when an electric force is connected to two ends of a copper wire?
11. What is an electric current?
12. What is the direction of electron flow?
13. What is the measure of the flow of free electrons in a material called?
14. Is the resistance of a material proportional to its length?

15. Is the resistance of a material inversely proportional to its cross-sectional area?

16. What is a resistor?

17. What energy is generated when current is flowing through a resistor?

18. Does the resistance of a pure metal increase as the temperature is raised? Why?

19. What is the electrical unit of resistance? Define?

CHAPTER II

PRIMARY CELLS

1. GENERAL

1.01 One method of obtaining direct current voltages for electrical equipment is by primary cells.

1.02 Chemical cells are divided into two classes, primary and secondary. A <u>primary cell</u> is one that generates an E.M.F. by virture of certain chemicals coming in contact with submerged metals or other substances which constitute the positive and negative terminals. A <u>secondary cell</u> stores electrical energy but does not directly generate an E.M.F. unless a current is first passed through the cell in a direction opposite to that in which it will flow when supplying energy to an external circuit.

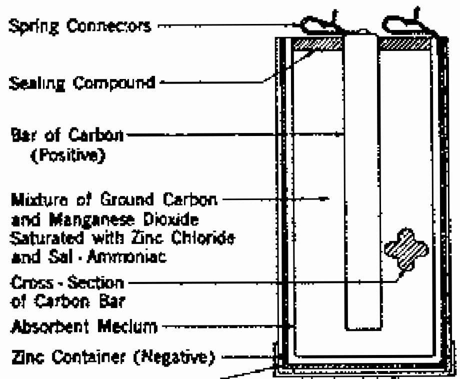
1.03 A dry cell is a primary cell and consists mainly of two dissimilar elements namely zinc and carbon, which are called electrodes, immersed in a solution of ammonium chloride and zinc chloride called the electrolyte.

1.04 The dry cell is enclosed in a zinc can which serves as the negative electrode and which is usually lined with blotting paper soaked in a solution of ammonium chloride and zinc chloride. The positive electrode consists of a central carbon rod surrounded by a "mix" of ground carbon and manganese dioxide moistened in a water solution of ammonium chloride and zinc chloride. The open end of the zinc can is closed by a layer of insulating compound, to hold the materials in place and to prevent evaporation of the moisture in the cell. Attached to the center carbon rod is the positive terminal and to the outside zinc case a negative terminal.

Figure 2-1 shows the construction of a typical dry cell.

1.05 The dry cell causes an electric current to flow by an electrochemical reaction which is not reversible and hence the cell, when discharged, cannot be recharged efficiently by an electric current.

1.06 When two or more cells are connected together, they are then said to be a <u>battery</u>.



BLUE BELL DRY CELL
FIG 2-1

2. THEORY OF OPERATION OF THE CELL

2.01 When the external circuit between the terminals of the dry cell is completed, chemical changes within the cell produce an excess of electrons on the negative terminal and an absence of electrons on the positive terminal which causes a difference of potential of $1\frac{1}{2}$ volts between the terminals. These changes result in the liberation of hydrogen which would tend to collect at the carbon electrode if it were not absorbed by the manganese dioxide in the "mix" which acts as a depolarizing agent.

2.02 In use, the various materials of the cell either become exhausted or coated with the products of chemical reactions, thereby increasing the <u>internal resistance</u> and the lowering the operating voltage of the cell.

2.03 Local internal action is responsible for the consumption of some of the chemical energy in the cell. This loss of useful energy, which occurs both while on open circuit and while in service is known as shelf depreciation.

2.04 The voltmeters in Figure 2-2 show that cell A and cell B which are made of the same substances, both produce the same voltage. The arrows point in the direction of electron current flow.

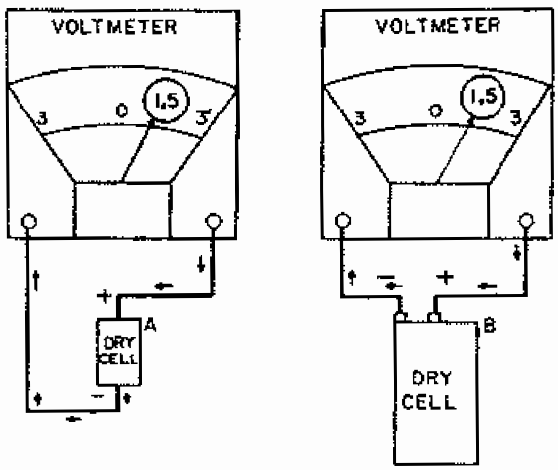


FIG. 2-2

2.05 In Figure 2-3 these cells are connected to identical circuits, and the meters indicate that 20 milliamperes are flowing in each case. It will be noted that the resistance in the external circuits (outside the cell) is largely controlling the current flow. The arrows point in the direction of electron current flow.

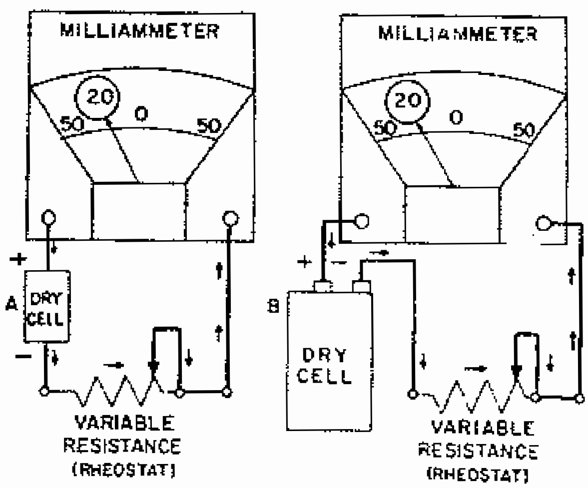


FIG. 2-3

2.06 In Figure 2-4 the external resistance of both circuits has been decreased by the same amount and 50 milliamperes now flow in each.

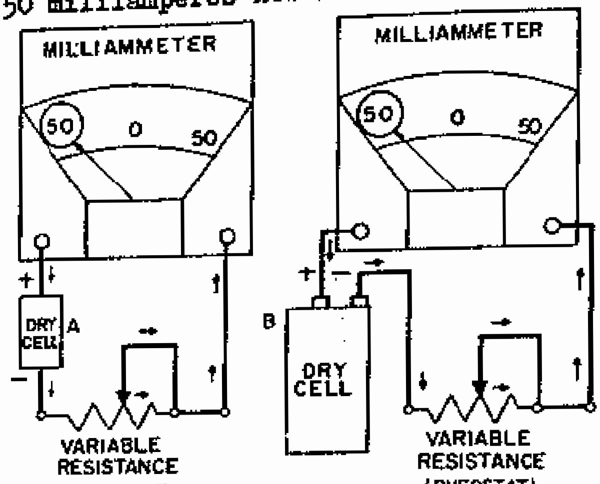


FIG. 2-4

2.07 However, in Figure 2-5, all of the external resistance has been removed, and cell A is causing one ampere to flow, while cell B produces a current of several amperes. It is seen that while the two cells produce the same E.M.F. (electro-motive force) and cause the same current to flow when connected to a comparatively high resistance external circuit, the maximum current producing capacity of the larger cell is greater than that of the smaller cell. The internal resistance of the large cell is less than that of the small cell and the internal circuit (internal resistance) is largely controlling the current flow so more current flows from cell B. This is due to the increased surface area of the electrodes of cell B.

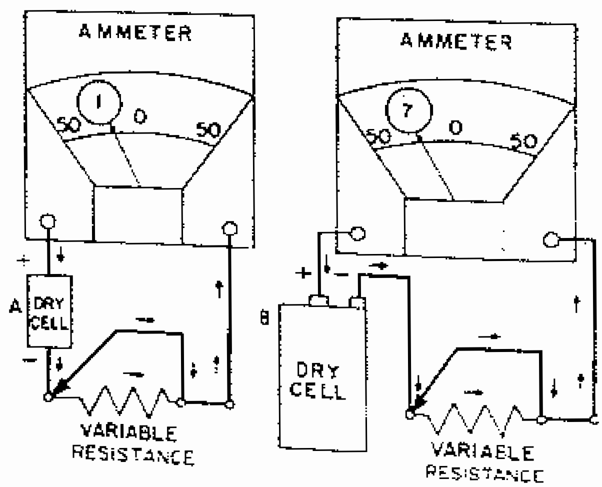


FIG 2-5

3. TESTING

3.01 The voltmeters in Figure 2-6 indicate that the new dry cell and the old one each produce about the same E.M.F.

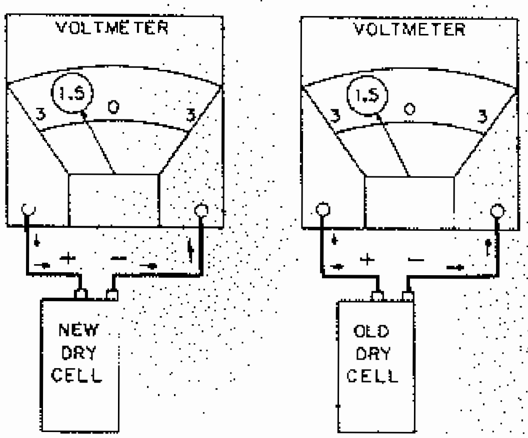


FIG. 2-6

However, when the cells are connected in a low resistance circuit, the voltage across the old cell drops a great deal while that across the new cell drops only slightly. (Figure 2-7) Thus, it is seen that a voltmeter in itself is not reliable for testing the condition of cells when they are not delivering considerable current.

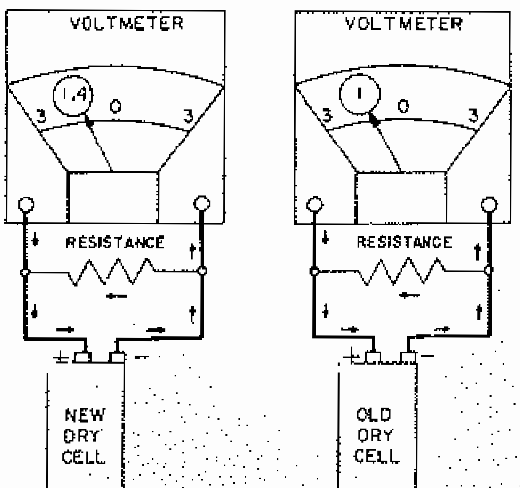


FIG. 2-7

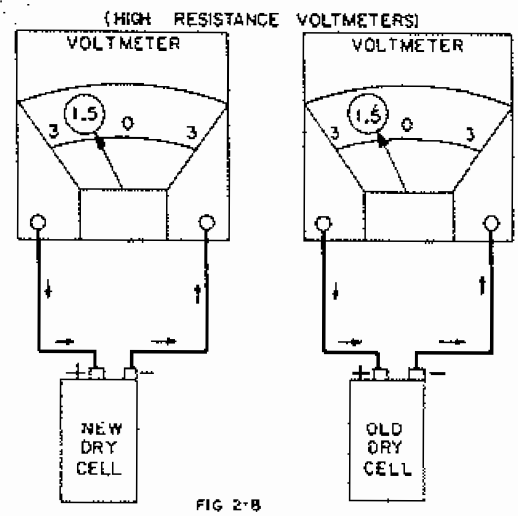


FIG 2-8

3.02 The voltmeters shown in Figure 2-8 are of the high resistance type so that only a little current flows through them. The indicated voltages of the new cell and of the old one are about the same. In Figure 2-9 the voltmeters have been replaced by ones of the low resistance type through which considerable current flows. In this case a higher voltage is indicated for the new cell than for the old one. Thus, it is seen that different types of voltmeters may not give the same readings when connected to a cell having a high internal resistance.

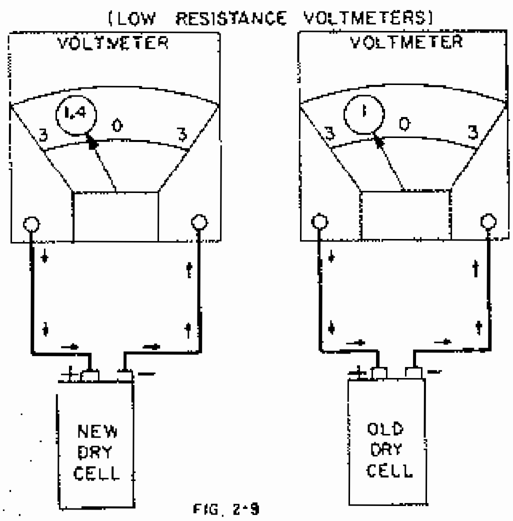


FIG. 2-9

3.03 In order to obtain accurate results in testing dry cells for a given use, it is necessary to specify the resistance of the voltmeter to be used, the amount of resistance across the terminals, and the length of time the resistance is to be connected before the reading is taken.

4. SYMBOLS

4.01 Schematic symbol for a cell, see Fig. 2-10. Schematic symbol for a battery, see Fig. 2-11.

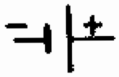


FIG. 2-10.

FIG. 2-11.

5. QUESTIONS

1. What three things make up a dry cell?

2. Which is the positive pole of a dry cell? Which is the negative?

3. Can a dry cell be fully recharged?

4. What electrode has an excess of electrons?

5. What is the E.M.F. of a primary cell?

6. Does a dry cell have an internal resistance? If so, when is the internal resistance of a cell the highest?

7. What determines a cell's current deldvering capacity?

8. Why may two voltmeters not give the same reading of an old dry cell?

9. How does a primary cell differ from a secondary cell?

10. How does a cell differ from a battery?

Chapter III

SECONDARY CELLS and STORAGE BATTERY

1. GENERAL

1.01 Another method of obtaining direct current voltages for electrical equipment is by use of secondary cells.

1.02 A secondary cell stores electrical energy but does not directly generate an E.M.F. unless a current is first passed through the cell in a direction opposite to that in which it will flow when supplying energy to an external circuit.

2. THEORY OF OPERATION

2.01 In Figure 3-1 two lead plates are immersed in a mixture of sulphuric acid and water. The voltmeter indicates that there is no potential difference between the plates. If direct current is caused to flow through the cell, bubbles may be seen to rise from the electrolyte and the plate connected to the positive terminal of the charging equipment gradually turns to a rich brown color, while the other plate changes to a light gray (Figure 3-2). If the voltmeter is connected to the plates, as in Figure 3-3, it will indicate that there is a difference of potential between the plates of about 2 volts. The lamp connected between the plates in Figure 3-4 shows that a current is flowing through it. If the lamp is left connected, the plates will gradually return to their original color, and after a time, the lamp will grow dim and finally become extinguished. If the cell were now tested with a voltmeter, it would be seen that no potential difference exists between the two plates.

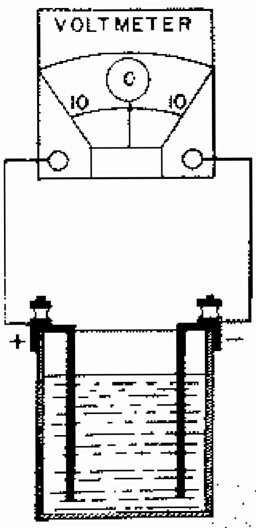


FIG. 3-1

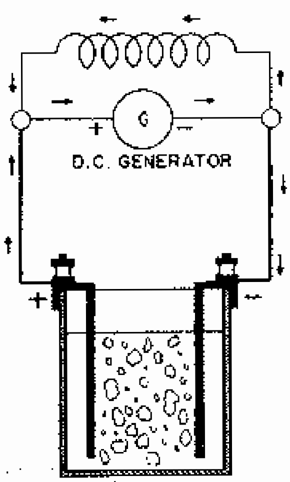


FIG. 3-2

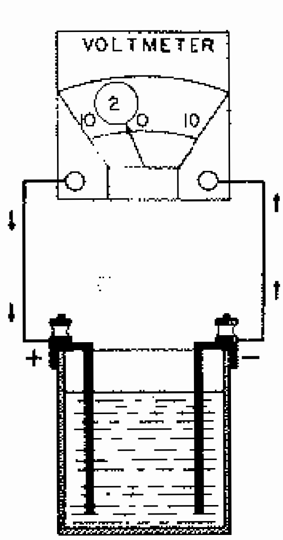


FIG. 3-3

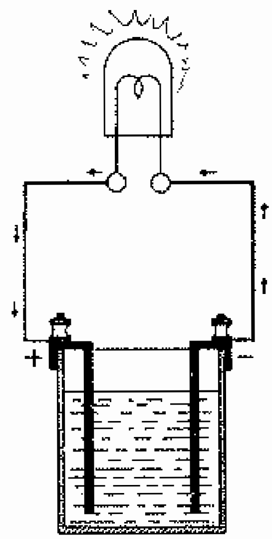


FIG. 3-4

2.02 The change of color of the plates is due to the fact that their chemical composition has changed. These plates in the electrolyte create an electromotive force and the cell is said to be charged. As the cell produces current the plates gradually return to their original chemical composition. This process is known as discharging, and a cell in this condition is said to be discharged.

2.03 The cell shown in Figure 3-5 is discharged and the hydrometer floats low in the electrolyte. As the cell charges the hydrometer gradually rises. This indicates that the electrolyte becomes heavier as the cell is charged (Figure 3-6). On the other hand, the electrolyte becomes lighter as the cell discharges so that the hydrometer floats lower (Figure 3-7).

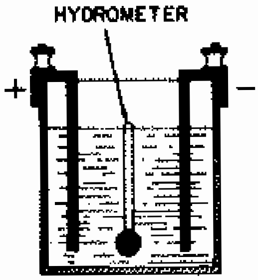


FIG. 3-5

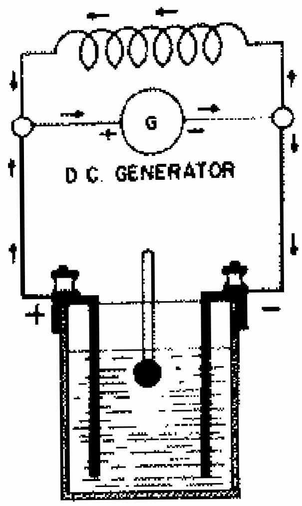


FIG. 3-6

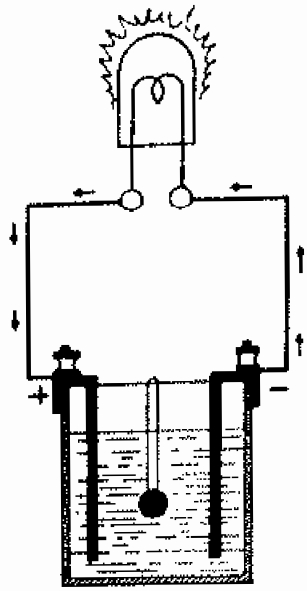


FIG. 3-7

Instead of saying that the electrolyte is heavier or lighter, we say that its specific gravity is high or low. The change in the specific gravity of the electrolyte is due to the fact that its chemical composition changes as the cell is charged or discharged, just as the chemical composition of the plates change.

2.04 It may be seen that the depth at which the hydrometer floats indicates the state of charge of a cell. However, different types of cells give different specific gravity readings when fully charged. For instance, the specific gravity of a fully charged automobile battery is higher than that of an ordinary telephone central office battery. It is therefore necessary to know what the specific gravity of a particular cell should be both when charged and discharged in order to interpret the hydrometer readings of it. In addition the specific gravity of a cell becomes less as its temperature increases. For this reason, where accuracy is required, it is necessary to know the temperature of the electrolyte at the time a reading is taken and how much allowance to make for temperature above or below normal.

3. TESTING STORAGE BATTERIES

3.01 The water in the electrolyte gradually evaporates so that it must be replaced. The specific gravity of water is considerably lower than that of sulphuric acid. It is, therefore, necessary to wait after adding water until it is thoroughly mixed with the acid before taking a hydrometer reading. Where accuracy is required, it is necessary to know the electrolyte level at the time a reading is taken and how much allowance to make for electrolyte level below normal.

3.02 The cell in Figure 3-8 is fully charged. The voltmeter will show that closing and opening the switch does not appreciably affect the voltage. However, if the cell is only partially charged, connecting a load to it greatly reduces the potential difference across its terminals (Figure 3-9). It may, therefore, be seen that a voltmeter reading of a storage cell is not generally a reliable indication of the cell's state of charge or of its ability to deliver current.

3.03 In Figure 3-10 a storage battery at the Private Branch Exchange (PBX) is being charged by the central office battery over a charging lead.

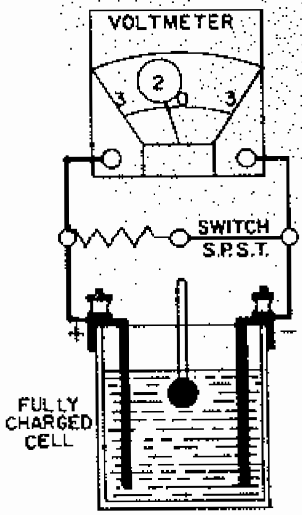


FIG. 3-8

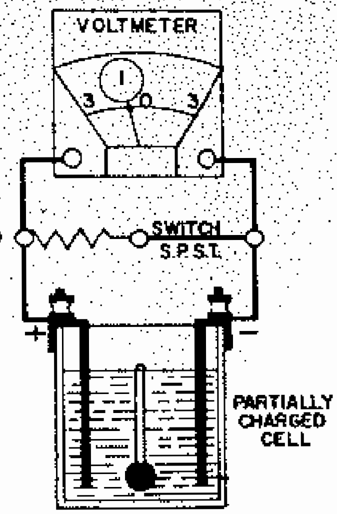


FIG. 3-9

The voltage across the P.B.X. battery is 17.1. However, if the charging lead is opened at the P.B.X. battery (Figure 3-11) the P.B.X. battery voltage is 17 and the voltage from the charging lead to ground is slightly under 48 volts. Thus, the voltage delivered to the P.B.X. equipment is not greatly affected when the charging lead is connected or disconnected.

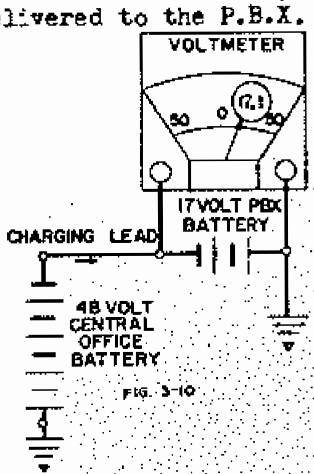


FIG. 3-10

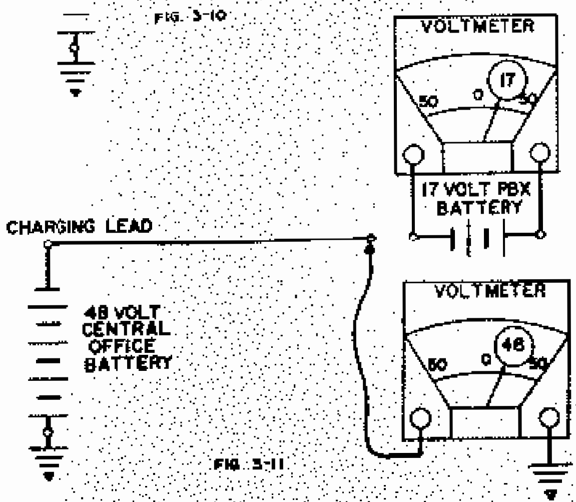


FIG. 3-11

4. CAPACITY OF STORAGE BATTERIES

4.01 The current producing capacity of a cell is directly related to two main factors. The area of the electrodes and the spacing of the electrodes directly controls the current delivering ability of any cell. These two factors are controlled in the manufacture of a cell or battery dependent upon the type of service for which it will be used.

4.02 In general, the size of the battery plates as well as their spacing affect the internal resistance of the battery. The goal of good battery manufacture is to keep the internal resistance as near zero as possible.

5. QUESTIONS

1. Why is a voltmeter not reliable for indicating the state of charge of a storage cell?

2. What is the purpose of a hydrometer? How does it function?

3. Do all storage cells have the same specific gravity when fully charged?

4. What effect would an open at point X in Figure 3-12 have upon the lamp?

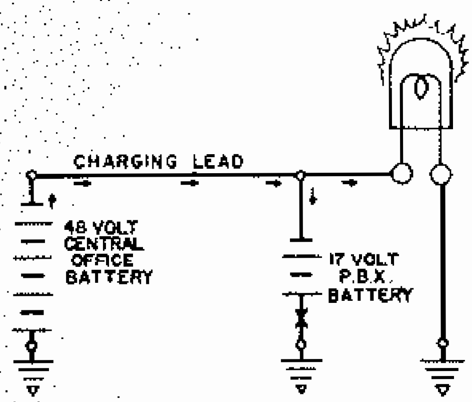


FIG. 3-12

CHAPTER IV

COMBINATION OF CELLS

1. CELLS IN PARALLEL

1.01 Two primary cells connected as shown in Figure 4-1 produce the same voltage as one cell alone and will cause the same current flow through a circuit having considerable resistance.

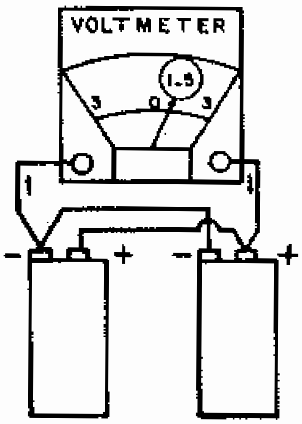


FIG 4-1

However, if they are connected to a circuit of low resistance as in Figure 4-2, more current will flow from the two cells than from the single one because the two cells have less internal resistance and the internal resistance is largely controlling the current flow. These cells are said to be connected in parallel or in multiple. If three such cells were so connected, the current capacity would be about three times as great, etc. That is adding identical cells in parallel increased the maximum current capacity but does not affect the voltage.

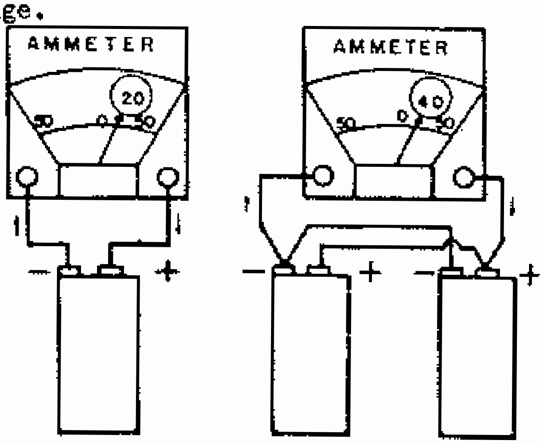


FIG 4-2

1.02 One of the primary cells shown in Figure 4-3 is connected reversed and tends to cause the current to flow in one direction through the lamp while the other tends to cause the current to flow in the other direction. The result is that current flows as indicated by the arrows, but only a negligible amount flows through the lamp. Thus it is important when connecting cells in parallel to make sure that like terminals are placed together.

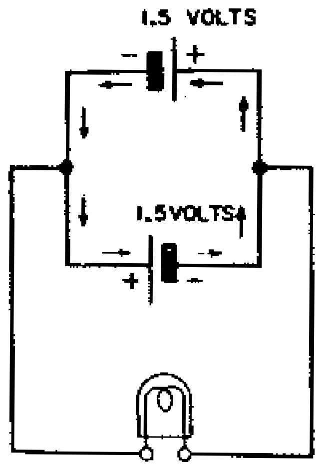


FIG. 4-3

2. CELLS IN SERIES

2.01 The primary cell shown in Figure 4-4 produces an electromotive force (EMF) of $1\frac{1}{2}$ volts and causes 1 ampere to flow through the circuit.

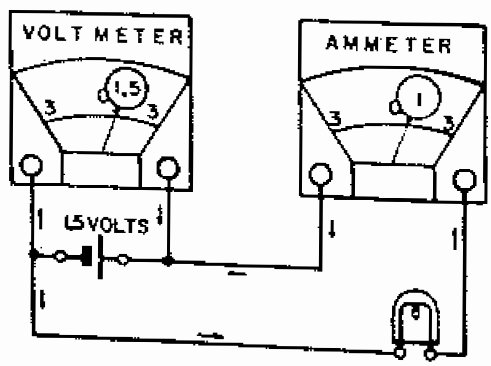


FIG 4-4

In Figure 4-5 two such cells are connected in the circuit so that all of the current which flows must go through both cells. It must be noted that the lamp in the external circuit is largely controlling the current flow. The voltmeter indicates that the two cells together produce an E.M.F. of 3 volts. Since the E.M.F. is doubled, the current flow is also twice as great.

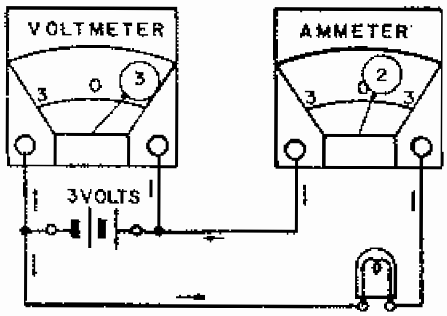


FIG 4-5

If more cells are connected in this manner, the E.M.F. is correspondingly increased. Cells so connected are said to be in series. The E.M.F. of a battery of similar cells connected in series is equal to the voltage of one cell multiplied by the number of cells.

2.02 The terminals of the primary cell represented in Figure 4-6 are connected by a wire of very low resistance. Likewise, the terminals of the two cell battery in Figure 4-7 are connected by a wire of very low resistance. The meters indicate that the current flow in the two circuits is about the same. This demonstrates that while increasing the number of cells in

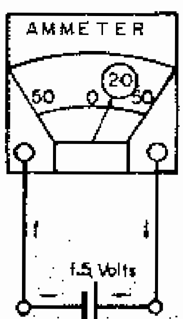


FIG. 4-6

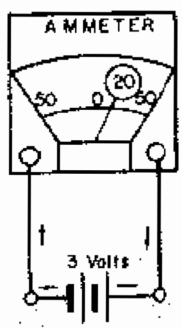


FIG. 4-7

series increases the voltage, it does not change the maximum current capacity, because when the voltage is doubled the resistance is doubled due to the internal resist-nce of the cells.

2.03 The primary cells in Figure 4-8 are connected so that one tends to cause the current to flow in one direction and the other cell tends to make the current go the other way. The result is that no current flows at all. One of the four cells in Figure 4-9 is reversed. This cell neutralizes one of the other three cells so that only two of the cells are effective, and the E.M.F. of the battery is only 3 volts instead of 6 volts. Thus, it is seen that it is important when placing cells either in parallel or in series to connect them so that they all tend to cause the current to flow in the proper direction.

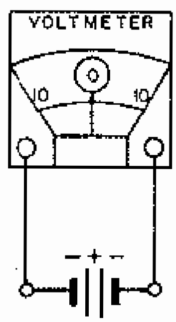


FIG 4-8

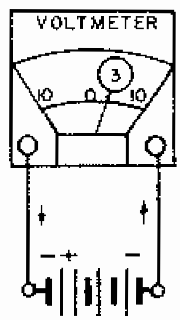


FIG 4-9

3. BATTERIES

3.01 Any combination of two or more cells, whether in series or parallel, is called a battery.

3.02 The voltage and the capacity of a battery can both be increased by connecting cells in one of the following ways:

1. As shown in Figure 4-10. These nine cells are said to be in parallel series because the series connected cells are placed in parallel.

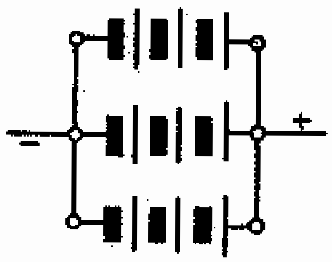


FIG 4-10

2. As shown in Figure 4-11. In this case the nine cells are said to be in series-parallel, because the parallel connected cells are placed in series.

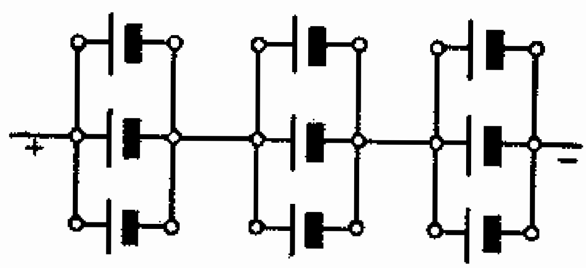


FIG 4-11

4. QUESTIONS

1. What is the advantage of connecting battery cells in series? In parallel?

2. What is the difference between a cell and a battery?

3. What is the rule for connecting cells in parallel? In series?

CHAPTER V

OHM'S LAW

1. GENERAL

1.01 A German physicist named George Simon Ohm was the first to discover the relation between electromotive force, current, and resistance in an electric circuit. The discovery is called "Ohm's Law" and simply expressed is - that for any circuit or part of a circuit under consideration the current increases as the electromotive force increases and decreases as the resistance increases. Stating this same relationship another way, we can say that the current in amperes is equal to the electromotive force in volts divided by the resistance in ohms.

This law, mathematically expressed, is as follows:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

1.02 If in the above expression we substitute the proper symbols (instead of amperes, volts and ohms) we have the following equation:

$$I = E \div R,$$

or, as more commonly expressed,

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

This is the equation for Ohm's Law. It is perhaps the most important one in all electrical work. It may be expressed in other forms, but when expressed as shown, permits us to calculate the current that may be expected in any circuit when we know the voltage of the source of electromotive force and when we know the resistance connected to this source in ohms.

Example: In Figure 5-1 if the electromotive force of the battery is 24 volts and the resistance of the lamp connected to it is 112 ohms, what will be the value of the current flowing through the lamp when the circuit is closed?

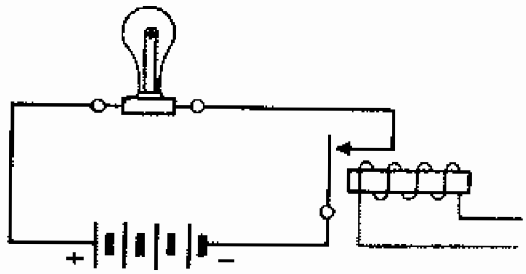


FIG 5-1

Solution: $E = 24$

$R = 112$

$$I = \frac{E}{R} = \frac{24}{112} = .21 \text{ ampere, ans.}$$

2. OTHER WAYS OF EXPRESSING OHM'S LAW

2.01 The equation above states that the current is equal to the electromotive force divided by the resistance; then by simple algebra the electromotive force must be equal to the current multiplied by the resistance, or the equation may be expressed,

$$E = RI$$

From this equation we may find the electromotive force acting in any circuit if we know the resistance and the current.

Example: In Figure 5-2 the resistance of the door bell winding is 4 ohms. If during the instant the circuit is closed the current is .2 ampere, what is the voltage of the dry cell?

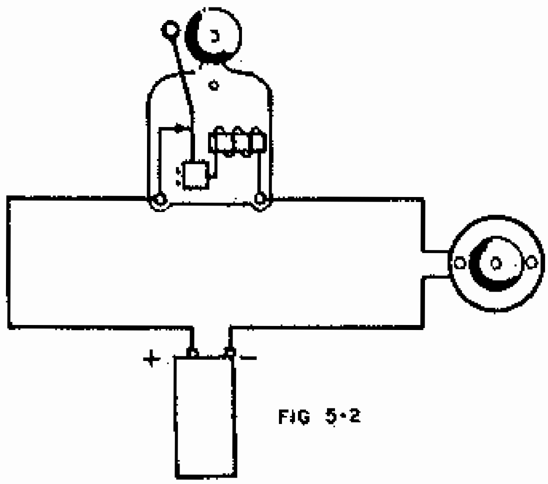


FIG 5-2

Solution: $R = 4$

$I = .2$

$E = RI = 4 \times .2 = .8$ volt, ans.

2.02 The third case is one where current and electromotive force are known and it is desired to find the resistance. Ohm's Law may likewise be stated to cover these conditions. If the electromotive force is equal to the resistance multiplied by the current, the resistance must be equal to the electromotive force divided by the current or, algebraically expressed,

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

Example: What is the res stance connected between the points a and b in Figure 5-3 if the voltage of the battery is 1.3 volts and the current is .5 ampere?

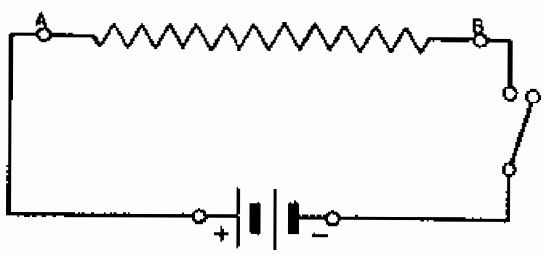


FIG 5-3

Solution: $E = 1.3$ volts

$I = .5$ ampere

$R = \frac{E}{I} = \frac{1.3}{.5} = 2.6$ ohms, ans.

3. A MEMORY AID FOR OHM'S LAW

3.01 An easy way to remember these three equations of Ohm's Law is to draw a circle and divide it in two with a horizontal line, placing E in the top half of the circle. Divide the lower half of the circle with a vertical line, placing I to the left of the line and R to the right of the line (Figure 5-4).

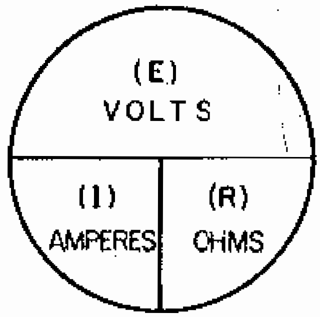


FIG.5-4

3.02 If you wish to find the voltage (E) place your thumb over E and you find E = I x R. If you wish to find the amperes (I) place your thumb over I and you find $I = \frac{E}{R}$ If you wish to find how many ohms (R) place your thumb over R and you find

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

4. SMALL CURRENTS

4.01 The current flow in most telephone circuits is only a small fraction of an ampere, and the meters used to measure these currents are marked off in milliamperes instead of amperes, a milliampere being one-thousandth of an ampere. Current flow meters so graduated are called milliammeters.

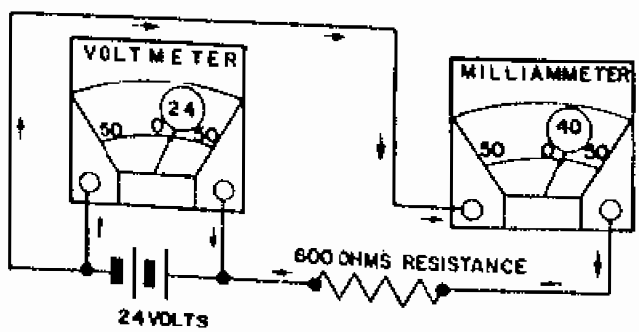


FIG. 5-5

4.02 The resistance of the circuit in Figure 5-5 is 600 ohms, and the battery produces an E.M.F. of 24 volts. If we wish to calculate the current flow we may substitute the value of the voltage and of the resistance in the equation:

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}}$$

We would then have:

$$\text{Amperes} = \frac{24}{600} = .040 \text{ amperes}$$

That is, the current is forty-thousandths of an ampere, or 40 milliamperes.

4.03 Suppose that we didn't know the resistance of the circuit in Figure 5-5 and the meter indicates that 60 milliamperes are flowing. We would find the resistance by means of the equation -

$$\text{Ohms} = \frac{\text{volts}}{\text{amperes}}$$

We know that the voltage of the battery is 24. In order for the equation to hold true, the current flow must be expressed in amperes. We know that one milliampere is $\frac{1}{1000}$ of an ampere, so that 60 milliamperes must be $\frac{60}{1000}$ of an ampere; more commonly written .060 amperes. Thus, the resistance $= \frac{24}{.060} = 400$ ohms.

5. QUESTIONS

1. What is the definition of an ohm?
2. What are the three ohm's law equations?
3. Current in ohm's law is expressed in milliamperes. True or false?
4. If a voltage of 6 volts is impressed across a resistance of 2 ohms, what is the total current in the circuit?
5. If it takes a 24 volt supply to light a switchboard lamp with .050 amperes flowing in the circuit what is the resistance of the lamp?
6. How many milliamperes are there in one ampere?
7. In a general analysis of a circuit where the external resistance is high, why is a battery assumed to have zero resistance?
8. In a general analysis of a circuit how much resistance does a voltmeter have? An ammeter? Short conducting wires?

CHAPTER VI

D.C. CIRCUITS

1. GENERAL

1.01 In telephone work it is often necessary to use two or more pieces of equipment in one circuit. These pieces of equipment may be connected in a number of different ways. All circuits may be divided into three general classes; series circuits, parallel circuits, and series-parallel circuits. In a d.c. circuit the only opposition offered to the flow of current is that due to resistance. The effects of combining several resistances in one circuit will now be considered.

2. RESISTANCES IN SERIES

2.01 A series circuit is one in which the same current flows in each part of the circuit. One of the circuits used in telephone work is the primary circuit of the local battery telephone. This is shown in Figure 6-1.

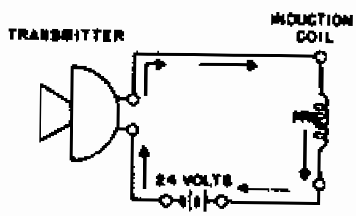


FIG. 6-1

In this circuit, all of the current which leaves the battery must first flow through the transmitter, then through the induction coil and back to the battery.

2.02 In an electrical circuit, the opposition to the current must be the sum of the individual oppositions which are in series. Thus, a 10-ohm resistor and two 20-ohm resistors connected in series make a total opposition of 50 ohms. This gives a law for the series circuit. IN A SERIES CIRCUIT THE TOTAL RESISTANCE IS THE SUM OF THE INDIVIDUAL RESISTANCES. Thus, for Figure 6-2.

$$R_t = R_1 + R_2 + R_3$$

2.03 IN A SERIES CIRCUIT THE SAME CURRENT FLOWS IN EACH PART OF THE CIRCUIT. For Figure 6-2

$$I_t = I_1 = I_2 = I_3$$

2.04 It is frequently important to know the voltage across any one of the resistances in a circuit. This voltage may be measured with a voltmeter connected across the individual resistances as shown in Figure 6-3, or may be calculated by Ohm's law.

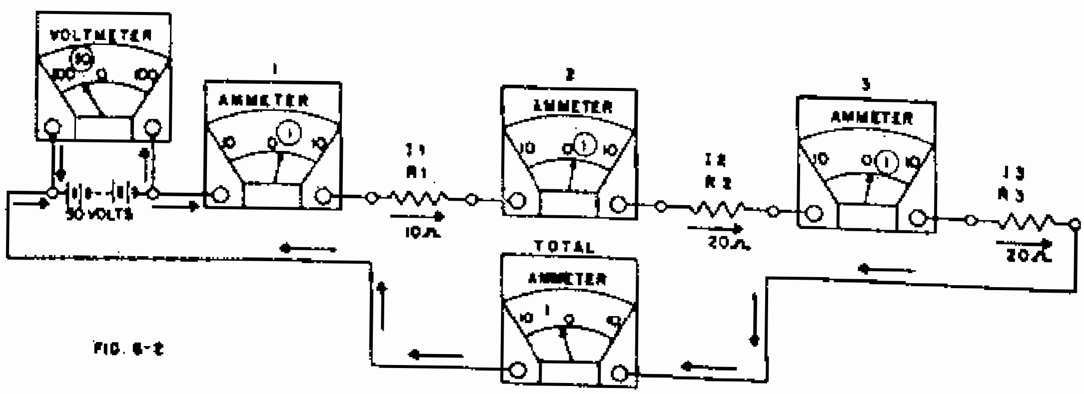


FIG. 6-2

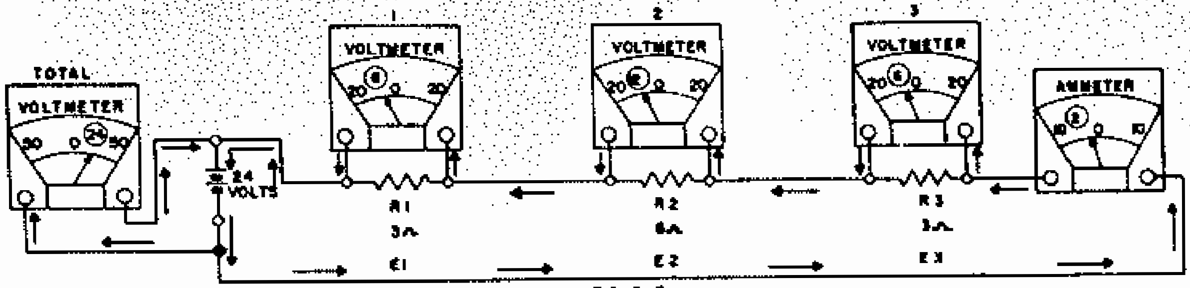


FIG. 6-3

In Figure 6-3, the ammeter will measure the current through the entire circuit and the values of E1, E2 and E3 will be the voltages across each piece of equipment. E1, E2 and E3 are called the <u>voltage drops</u>, or <u>IR drops</u> (current resistance drops). The total resistance of the circuit will be 12 ohms and the current flowing will be E÷ R or 24 ÷ 12 which equals 2 amperes. These 2 amperes must flow through the entire circuit, and by applying Ohm's law to each part of the circuit the IR drop can be calculated. Thus, the voltage drop across resistor 1 is 2 x 3 or 6 volts. Across resistor 3, the voltage drop is also 2 x 3 or 6 volts and across resistor 2, the voltage drop is 2 x 6 or 12 volts. The total voltage drop will be:

$$E_1 + E_2 + E_3 = 24 \text{ Volts}$$

This result illustrates another law for series circuits. IN A SERIES CIRCUIT THE SUM OF THE VOLTAGES ACROSS THE INDIVIDUAL RESISTANCES IS EQUAL TO THE APPLIED VOLTAGE. This is called <u>Kirchoff's voltage law</u>.

2.05 Three laws of a series circuit which are now summarized should be committed to memory:

a. In a series circuit the total resistance is the sum of the individual resistances.

b. In a series circuit the same current flows in each part of the circuit.

c. In a series circuit the sum of the voltages across the individual resistances is equal to the applied voltage.

3. <u>PARALLEL CIRCUITS</u>

3.01 In the series circuits explained in the preceeding paragraph only one path was provided through which the current might flow.

3.02 There is also a type of circuit which will provide more than one path through which current may flow. These circuits are known as parallel circuits. A parallel circuit is one in which one terminal of each element is connected to a common point to form one terminal of the system, and the other terminal of each element is connected to a second common point to form the other terminal of the system.

3.03 In Figure 6-4 the same voltage which is applied to RI is also applied to R_2 and to R3 This is true because the corresponding points of each resistor are connected to the same points, a and b, and the same

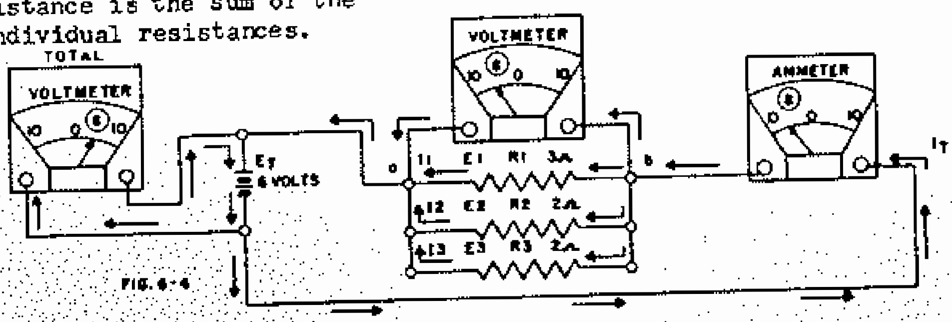


FIG. 6-4

difference of potential must exist between points a and b for all three resistances. This illustrates the first law of a parallel circuit. IN A PARALLEL CIRCUIT THE SAME VOLTAGE IS APPLIED TO EACH ELEMENT. For Figure 6-4, $E_t = E_1 = E_2 = E_3$

3.04 If an additional path is provided in a circuit through which the current may flow, the total current in the circuit must be the original plus that of the added path. In Figure 6-4, if R_1 only is connected to the 6-volt source, it is known by Ohm's law ($I = E \div R$) that the current is $6 \div 3 = 2$ amperes. When R_2 is added, the same voltage is applied to it as was applied to R_1. The current through R_2 must equal $6 \div 2 = 3$ amperes. The total current flowing from the source is now $2 + 3 = 5$ amperes. When R_3 is added, the total current from the battery will be increased another 3 amperes or will equal $2 + 3 + 3 = 8$ amperes. From these results, the following rule for parallel circuits may be stated. THE TOTAL CURRENT IN A PARALLEL CIRCUIT IS EQUAL TO THE SUM OF THE CURRENTS FLOWING IN THE INDIVIDUAL BRANCHES. For Figure 6-4 $I_t = I_1 + I_2 + I_3$.

3.05 Since the total current in the circuit and the applied voltage are both known, the total resistance may be calculated.

$R_t = E_t \div I_t = 6 \div 8 = 0.75$ Ohms

From this result another rule for parallel circuits may be stated. THE TOTAL RESISTANCE OF A PARALLEL CIRCUIT IS EQUAL TO THE APPLIED VOLTAGE DIVIDED BY THE TOTAL CURRENT. Compare the total resistance R_t with the individual resistances R_1, R_2 and R_3. R_t in this case equals 0.75 ohm and is less than either R_1, R_2 or R_3. Always remember that in a parallel circuit the combined or total resistance of the elements will be less than the resistance of the smallest element.

3.06 The three laws of a parallel circuit which are now summarized should also be memorized:

a. In a parallel circuit the same voltage is applied to each element.

b. The total current in a parallel circuit is equal to the sum of the currents flowing in the individual branches.

c. The total resistance of a parallel circuit is equal to the applied voltage divided by the total current.

4. COMBINING PARALLEL RESISTANCES

4.01 A method of determining the total resistance of a parallel circuit was shown in the preceeding paragraph. This is satisfactory provided the total current is known.

4.02 In the usual case the total current is not known and other means must be used for finding the total resistance. The simplest case is that of several equal resistors connected in parallel. To solve this problem divide the resistance of one piece of equipment by the number of pieces connected in parallel. If two 10-ohm resistors are connected in parallel, the total resistance offered by the combination is $10 \div 2 = 5$ ohms. If three 12-ohm resistors are in parallel $R_t = 12 \div 3 = 4$ ohms, and if five 10-ohm resistors are in parallel $R_t = 10 \div 5 = 2$ ohms. Stated as a rule, THE TOTAL RESISTANCE OF EQUAL RESISTANCES CONNECTED IN PARALLEL IS EQUAL TO ONE RESISTANCE DIVIDED BY THE NUMBER CONNECTED.

4.03 Unfortunately, all equipment used in electrical circuits does not have the same resistance. Therefore, when different pieces of equipment are connected across a battery, they do not all draw the same current. Two unequal resistors connected in parallel are shown in Figure 6-5

FIG 6-5

The current through resistor A would be,

$$I_A = \frac{E}{R_A} = \frac{24}{12} = 2 \text{ amperes}$$

The current through resistor B would be,

$$I_B = \frac{E}{R_B} = \frac{24}{4} = 6 \text{ amperes}$$

The total current from the battery is equal to the sum of the currents in the branches, or,

$$I_T = 6 + 2 = 8 \text{ amperes}$$

Ohm's law will give the total resistance offered by the circuit,

$$R_T = \frac{E}{I_T} = \frac{24}{8} = 3 \text{ ohms}$$

4.04 Obviously, the rule for equal resistors in parallel could not be used for this circuit as the individual resistors A and B are not equal in value. For such cases, another method has been found for the calculation of the total resistance. This method may be stated as follows: THE TOTAL RESISTANCE OF TWO RESISTANCES IN PARALLEL IS EQUAL TO THEIR PRODUCT DIVIDED BY THEIR SUM.

Applying the new rule to the circuit of Figure 6-5

$$R_T = \frac{\text{Product}}{\text{Sum}} = \frac{12 \times 4}{12 + 4} = 3 \text{ ohms}$$

which is the same answer as when the applied voltage was divided by the total current.

The product over sum method may be applied to any two resistances in parallel whether they are equal or not. It is the most commonly used method of determining the resistance of a parallel circuit. It may be extended to include three or more unequal resistances in parallel by determining first the resistance of two of the resistances in parallel, and then combining the result of this calculation with one of the remaining resistances by another application of the same rule. In each case, the result of the previous calculation is combined with one of the remaining resistances until all the resistances are included. For example, consider the circuit shown in Figure 6-6 which consists of three unequal resistors connected in parallel.

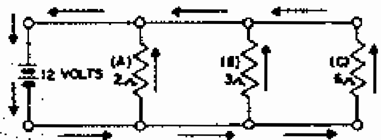


FIG. 6-6

Apply the rule first to resistances B and C.

$$R_T = \frac{\text{Product}}{\text{Sum}} = \frac{3 \times 6}{3+6} = \frac{18}{9} = 2 \text{ ohms.}$$

Combine this result (2ohms) with the remaining resistance A, of 2 ohms.

$$R_T = \frac{\text{Product}}{\text{Sum}} = \frac{2 \times 2}{2+2} = \frac{4}{4} = 1 \text{ ohm.}$$

This result (1 ohm) is the total resistance of the three resistances A, B and C in parallel. This may be proven by calculating the total current, and from this, the combined resistance by Ohm's law as was done for Figure 6-4.

4.05 There is yet another way of finding the total resistance of several resistances in parallel. This is called the reciprocal method. (The reciprocal of a number is one divided by that number.) As has been previously stated, the product over sum method can only be used with two resisters at one time, and so, if as many as five or six resistors are in parallel, the arithmetical solution will be quite tedious. The reciprocal method may be used to find the total resistance of any number of resistances in one operation. The rule is as follows: THE TOTAL RESISTANCE OF A PARALLEL CIRCUIT IS EQUAL TO THE RECIPROCAL OF THE SUM OF THE RECIPROCALS OF THE INDIVIDUAL RESISTANCES.

Stated as a formula,

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

In Figure 6-6,

$$R_T = \frac{1}{1/2 + 1/3 + 1/6}, \text{ or}$$

$$R_T = \frac{1}{.5 + .33 + .17}, \text{ or}$$

$$R_T = \frac{1}{1} = 1 \text{ ohm.}$$

4.06 If the combined resistance of only two resistances in parallel is required, the product over sum method is probably the easier to use. If the combined resistance of three or more resistances is required, the reciprocal method may be the better. When in doubt, the work can be proved by assuming an applied voltage and using Ohm's law to determine total current and resistance.

5. SERIES-PARALLEL CIRCUITS

5.01 SERIES-PARALLEL circuits consist of groups of parallel resistances in series with other resistances. Any leg of a parallel group may consist of two or more resistors in series.

5.02 Series-parallel circuits may be solved by application of the rules already given for series and parallel circuits. To do this, the series-parallel circuit is reduced to an equivalent, simplified circuit. Each group of parallel resistances is first replaced by its equivalent single resistance and the entire circuit is then treated as a series circuit. Refer to Figure 6-7,

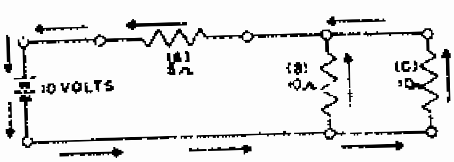


FIG 6-7

The first step is to reduce the two parallel resistances B and C to an equivalent single resistance. As B and C are equal, divide 10 by 2 which gives 5 ohms as the total resistance. The circuit is now a series circuit of two 5 ohm resistances. The total resistance is obtained by adding resistance A to the equivalent of B and C. This gives 5 plus 5, or 10 ohms as the resistance of the entire circuit. Knowing this, the total current is calculated by means of Ohm's law.

$$I_T = \frac{E}{R_T} = \frac{10}{10} = 1 \text{ ampere.}$$

This 1 ampere flows through resistor A, giving a voltage drop of 5 volts. As the two parallel resistances have the same value, the 1 ampere of current divides equally between the two. The IR drop across B equals 1/2 x 10, or 5 volts and across C is 1/2 x 10, or 5 volts also. This demonstrates the rule that each element of a parallel circuit is across the same voltage. By following one complete path around the circuit it can be shown that the sum of the voltage drops is equal to the applied voltage. Starting from the negative side of the battery there is a 5-volt drop in resistor B, another 5-volt drop in resistor A, and thus back to the battery. Following a path through resistor C will obtain the same result. Care must be taken to follow only one path at a time in tracing through a circuit.

5.03 The following combinations of resistors are given as examples for the student to follow in order that he may be able to work out similar problems encountered in this course and in those to follow.

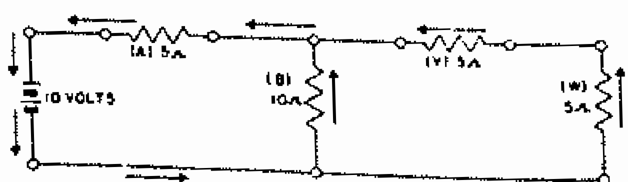


FIG 6-8

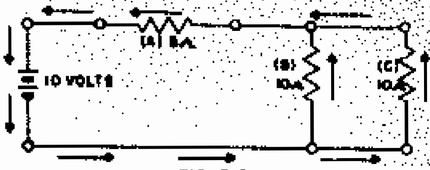


FIG. 6-9

Figure 6-9 is equivalent to Figure 6-8 since resistance C of Figure 6-9 (10 ohms) is equivalent to the resistance of resistors V and W of Figure 6-8 (5 ohms each) in series. From this point on, the solution of Figure 6-8 is the same as that for Figure 6-7 which has already been given.

5.04 Consider now the circuit shown in Figure 6-10,

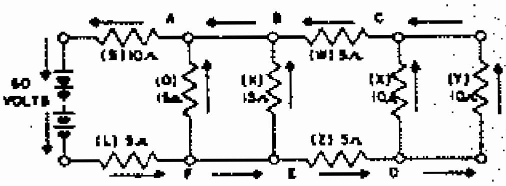


FIG. 6-10

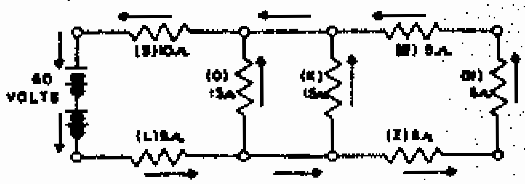


FIG. 6-11

The steps in the solution of Figure 6-10 are as follows:

1. Combine resistors X and Y, replacing them by resistance N of Figure 6-11. X and Y are equal and in parallel, therefore,

$$N = \frac{10}{2} = 5 \text{ ohms.}$$

Figure 6-11 is equivalent to Figure 6-10.

2. Combine resistors W, N and Z into a single resistor M of Figure 6-12. W, N and Z are in series, therefore, $M = 5+5+5 = 15$ ohms.

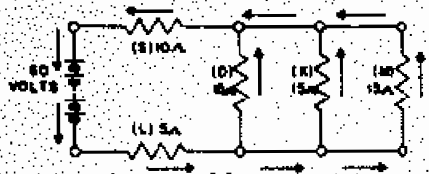


FIG. 6-12

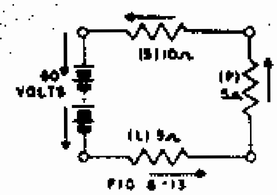


FIG. 6-13

3. Combine resistors O, K and M into a single resistance P of Figure 6-13. O, K and M are equal and in parallel, therefore,

$$P = \frac{15}{3} = 5 \text{ ohms.}$$

4. Combine resistors S, P and L which are in series. R of the whole circuit equals $10 + 5 + 5 = 20$ ohms.

5.

$$I_T = \frac{E}{R_T} = \frac{60}{20} = 3 \text{ amperes.}$$

6. Voltage drop across S.

$$E_S = I_T R_S = 3 \times 10 = 30 \text{ volts.}$$

7. Voltage drop across L.

$$E_L = I_T R_L = 3 \times 5 = 15 \text{ volts.}$$

8. Voltage drop across equivalent resistance P.

$$E_P = E_{total} - E_S - E_L = 60-30-15=15 \text{ volts.}$$

9. Current in resistor O.

$$I_O = \frac{E_O}{R_O} = \frac{15}{15} = 1 \text{ ampere.}$$

Note that $E_P = E_O$ because parallel resistors are across the same voltage.

10. At point F, in Figure 6-10, there are two paths for the current to flow. In a parallel circuit, the total current equals the sum of the currents in the branches. Therefore, the current flowing from point F to point E equals I_T minus I_0 or 3-1=2 amperes.

11. The voltage drop across parallel resistors is equal, so the voltage drop across K is 15 volts and the current through K is $\frac{15}{15} = 1$ ampere.

12. Since a current of 2 amperes flows from point F to point E, and 1 ampere of this current flows through resistance K, the current through Z must be 2-1=1 ampere.

13. At D the current again divides. Since the resistances of X and Y are the same, the current divides equally with ½ ampere going through each resistor.

14. The voltage drops across X and Y will be the same. ½ x 10 = 5 volts.

15. At C the two currents of ½ ampere each, join and 1 ampere flows through W. The voltage drop across W is 1 x 5 =5 volts.

16. At point B the currents through W and K join, and 2 amperes flow from point B to A.

17. At point A the current flowing through O joins the current flowing from Point B to A and 3 amperes flow through S.

5.05 We have been using a new law in the solution of this problem, called Kirchoff's current law. The law is as follows: THE SUM OF A CURRENT FLOWING TO A POINT OR JUNCTION IS EQUAL TO THE SUM OF THE CURRENT FLOWING AWAY FROM THE JUNCTION.

5.06 Any complicated series-parallel circuit can be solved in a similar manner by applying Ohm's law, Kirchoff's laws and the rules developed for series and parallel circuits.

6. PARALLEL CIRCUITS CONNECTED TO AMPLE CURRENT SUPPLY

6.01 A large wire having practically no resistance is used to make the connections in Figure 6-14. The switchboard lamp A is burning brilliantly.and its resistance is largely limiting the amount of current flowing. When the key is closed, Figure 6-15, practically twice as much current flows and both lamps light brilliantly.
That is, the rate of current flow through lamp A is not appreciably affected when the key is opened or closed.

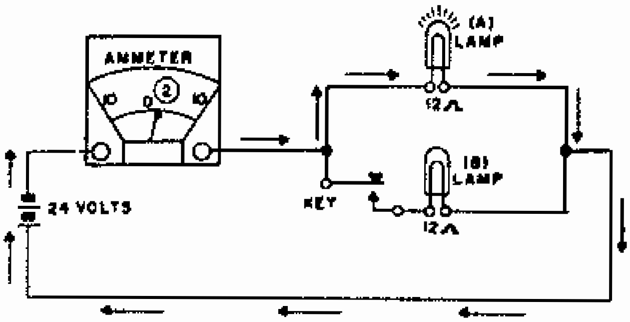


FIG 6-14

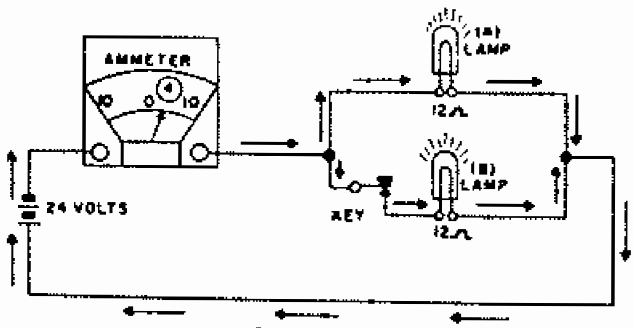


FIG 6-15

6.02 One large battery having a current capacity of several hundred amperes is used in a telephone central office to furnish a current supply through the transmitters of telephones being used as well as through relays, lamps and other apparatus. In Figure 6-16 one circuit is connected to such a battery, and 100 milliamperes is flowing through it. In Figure 6-17 a number of parallel circuits have been added and 100 milliamperes still flow through the original circuit. The point is that if a circuit is connected directly to an ample current supply, the current flow through it is not affected by the operation of circuits parallel to it.

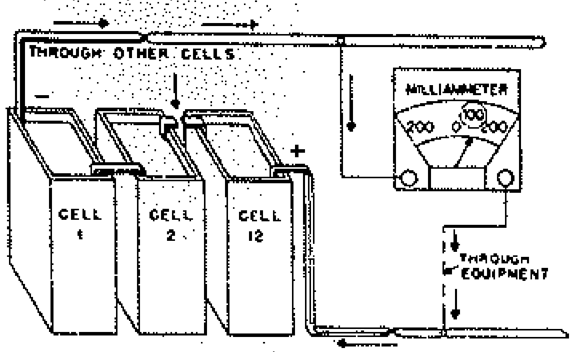


FIG 6-16

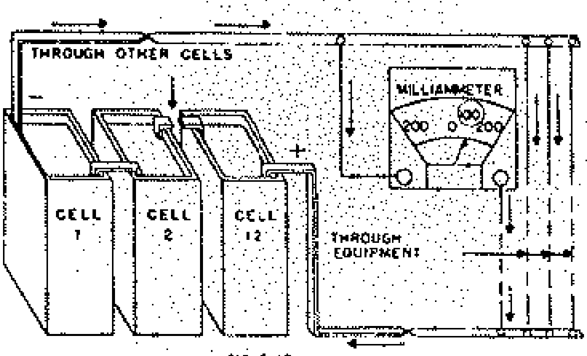


FIG 6-17

7. SPLIT PATHS AND SHUNTING

7.01 The resistance wire in Figure 6-18 largely controls the amount of current flowing in the circuit so that the ammeter reading is not greatly increased when the key is closed. With the key open, all of the current must flow through lamp A, but when the key is closed, half of the current flows through B causing it to light dimly (Figure 6-19). However, this leaves only half as much to flow through lamp A. We say that Lamp B shunts lamp A. The 95 ohm resistance is largely controlling the current flow.

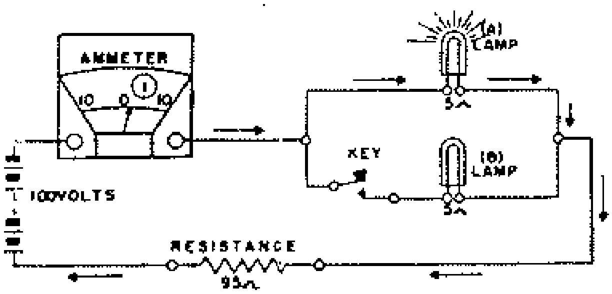


FIG 6-19

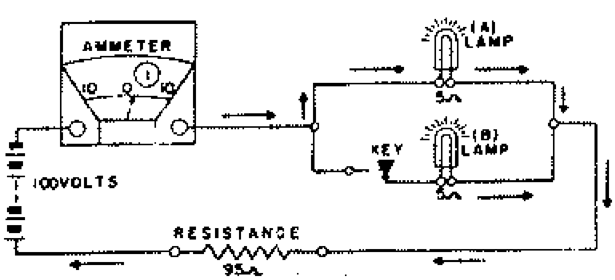


FIG 6-19

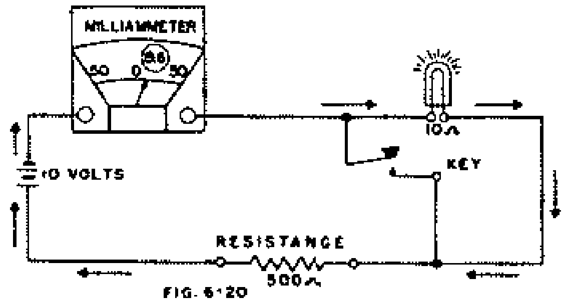


FIG. 6-20

7.02 The resistance in Figure 6-20 largely controls the current flow. When the key is closed (Figure 6-21), the current flow is increased very little, but practically all goes through the key. The key is said to be a dead shunt across the lamp.

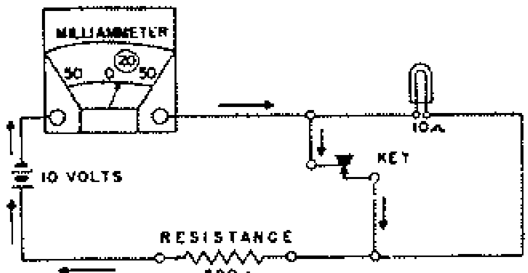


FIG 6-21

7.03 The wires in Figure 6-22 have appreciable resistance. It may be seen that the voltmeter and its connecting wires are in parallel with the section of wire between the points a and b, so part of the current flows through the meter as indicated by the arrows. In Figure 6-23 the meter and

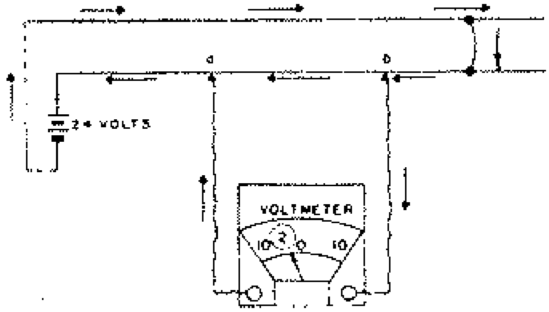


FIG 6-22

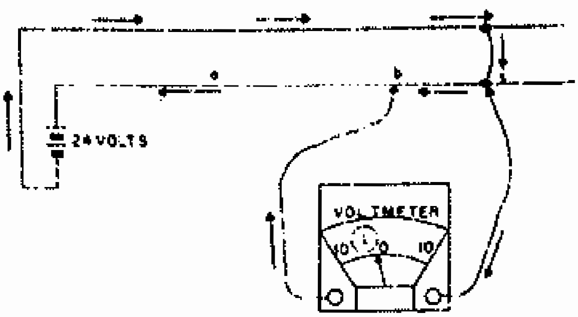


FIG 6-23

its connecting wires are in parallel with the part of the wire between points b and a. As the resistance of the section of wire b - a is small as compared to a - b less current flows through the meter in Figure 6-23. As there is no current flowing in the section of wire a - c in Figure 6-24 there is no current flowing in the meter.

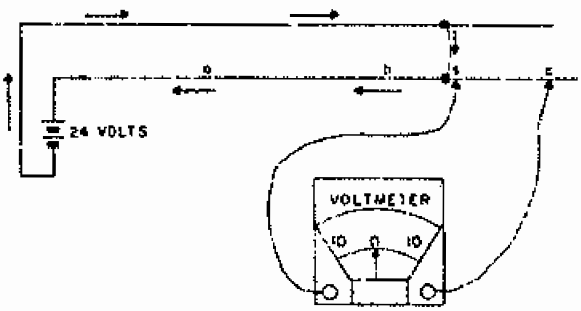


FIG. 6-24

7.04 The moment that the receiver in Figure 6-25 is connected to the wire, a faint click will be heard. When the path through the receiver is broken, a click will again be heard. Thus either a receiver or a voltmeter can be used to tell if current is flowing in a wire without disturbing the circuit. This type of test is often used where it is not practical to open the circuit at the required points, and is referred to as a split receiver test.

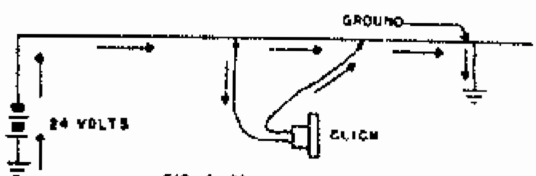


FIG. 6-25

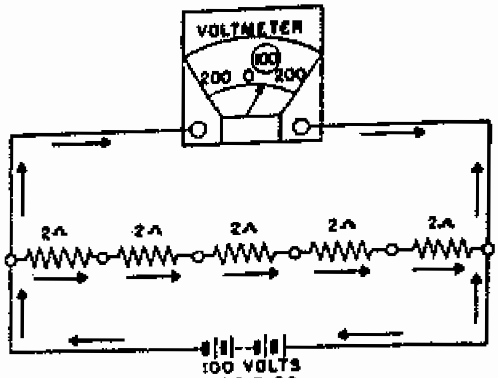


FIG. 6-26

8. THE POTENTIOMETER

8.01 Current is flowing through the resistances in Figure 6-26 and the meter indicates that the voltage drop across all of them is 100 volts.

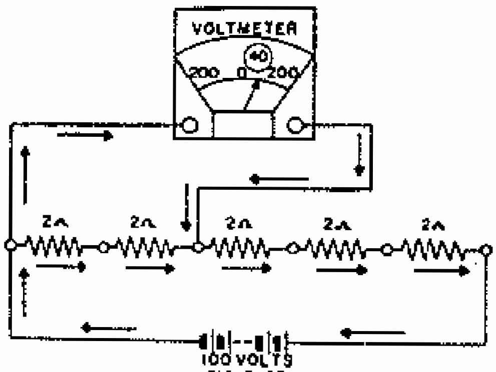


FIG 6-27

The meter in Figure 6-27 indicates that the voltage drop across two of the resistances is 40 volts, which is four-tenths of the voltage across all of them. Likewise, it would be found that the potential difference across half of the resistance is 50 volts, etc. Voltages from 0 to 100 may be obtained across terminals 1 and 3 of Figure 6-28 by moving the sliding contact 3 from terminals 1 to 2. Such a device is called a Potentiometer.

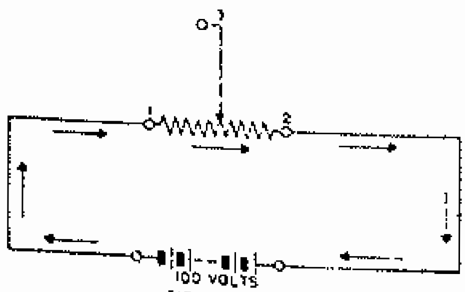


FIG 6-28

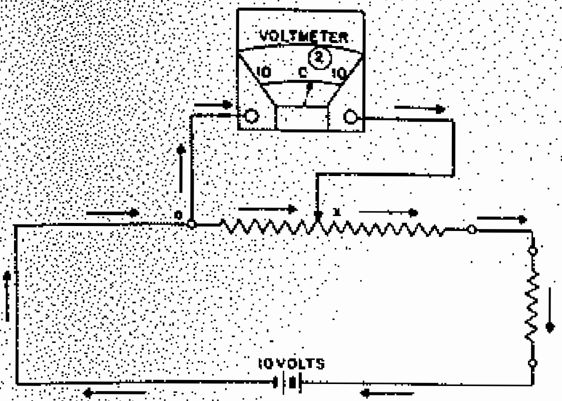


FIG. 6-29

8.02 The voltmeter in Figure 6-29 indicates that the potential difference between a and x is two volts.

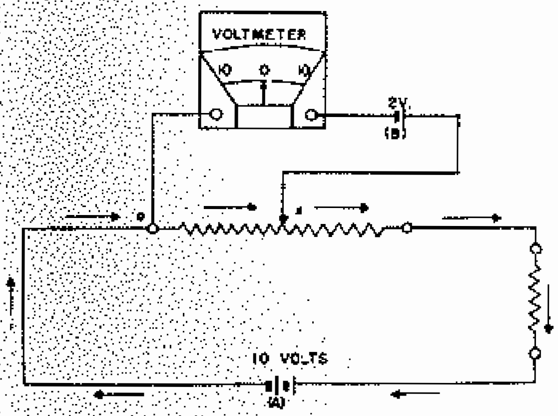


FIG. 6-30

This exactly balances the E.M.F. of Cell B in Figure 6-30, so that no current flows through the meter. Less resistance is included in Figure 6-31, so that the potential difference between a and x is less than two volts; consequently, Cell B causes current to flow

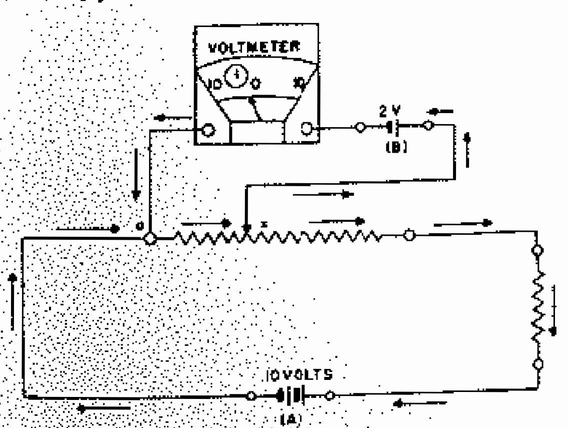


FIG. 6-31

through the meter as shown. On the other hand, more resistance is included between a and x in Figure 6-32, so that current is forced backward through Cell B. Thus it is seen that an E.M.F. may be balanced by the potential difference between two points of a circuit.

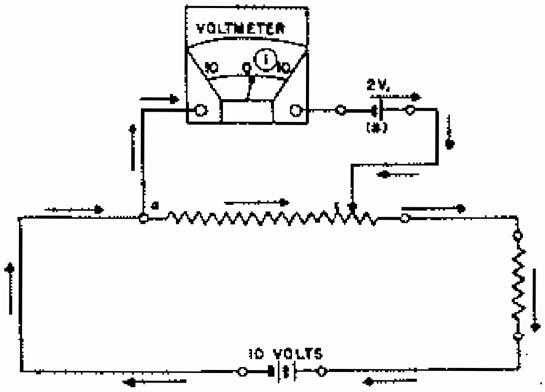


FIG. 6-32

9. THE WHEATSTONE BRIDGE

9.01 In Figure 6-33 a resistance totaling 100 ohms and one of 10 ohms are connected in parallel. The same potential difference, equal to the voltage of the battery, exists across each of them. Likewise, the potential difference across one-fifth of either resistance would be one-fifth of the battery voltage, etc.

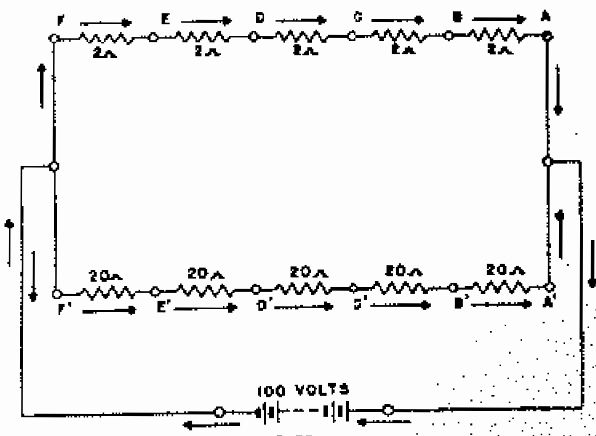


FIG. 6-33

Thus, the same potential difference exists between either end and the corresponding point of either branch. This means that there is no difference of potential between these two points. Therefore no current flows through the meter in Figure 6-34.

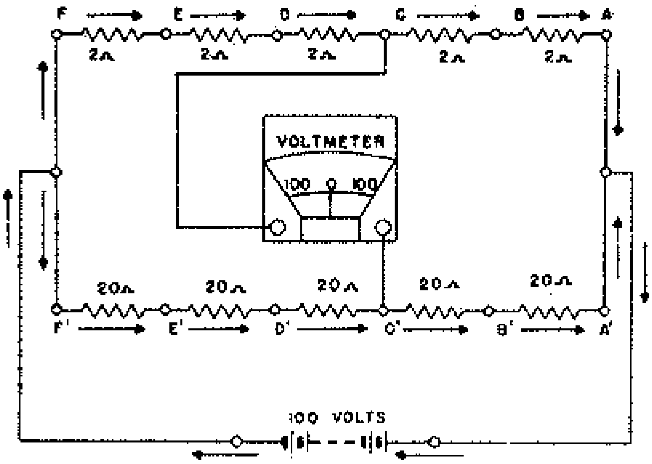


FIG 6-34

In Figure 6-35 the meter is connected to C and B'. Since C is at a higher potential than B, current flows through the meter as indicated.

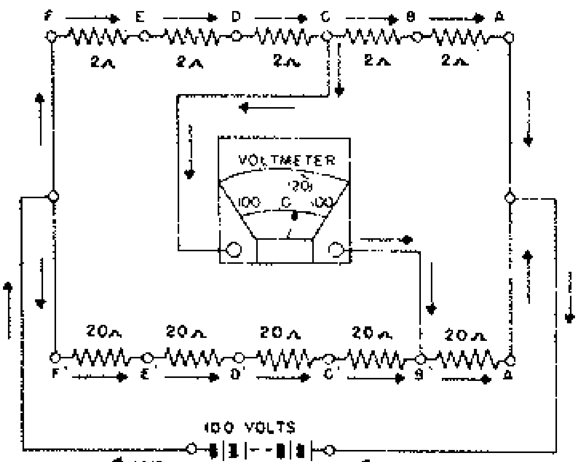


FIG 6-35

Point D' in Figure 6-36 is at a higher potential than C so that current flows through the meter in the opposite direction.

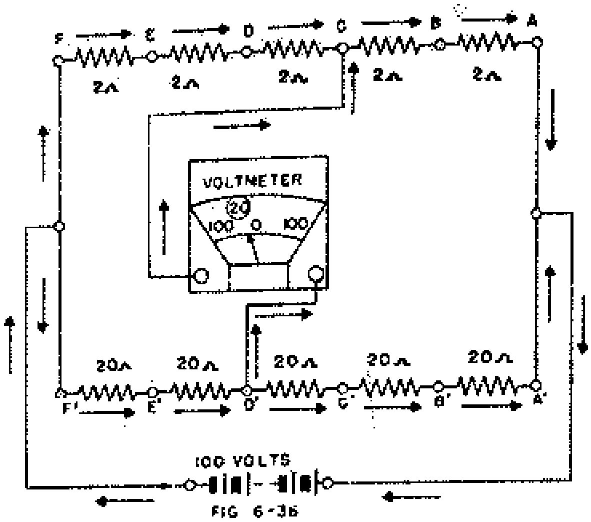


FIG 6-36

9.02 The values of R and R_1 in Figure 6-37 are known, but X is not known. R_2 is variable but can be read from the position of the sliding contact. If R_2 is adjusted so that no current flows through the meter, we say that the bridge is balanced. With the bridge balanced it may be shown that

$$\frac{R2}{R} = \frac{X}{R1} \quad \text{or} \quad X = \frac{R2\ R1}{R}$$

Thus the resistance of X may be determined. This device is known as a <u>Wheatstone Bridge</u>.

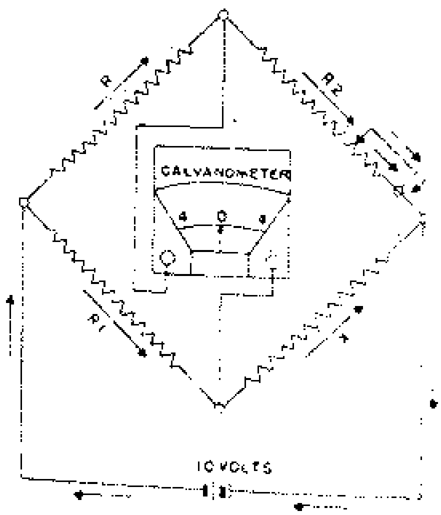


FIG 6-37

R and R^1 are known as the ratio arms, and are usually in the ratios 1:1, 1:10, 1:100, etc., so that calculation is easy. This method of determining unknown resistances is quite accurate.

10. QUESTIONS

1. How is the total resistance of a series circuit determined if the values of the individual resistors are known?

2. Does each piece of equipment in a series circuit have the same current flowing through it?

3. What does the sum of the separate voltage drops in a series circuit equal?

4. Is a series circuit limited to two pieces of equipment?

5. In a series circuit containing two pieces of equipment of unequal resistance, which piece of equipment will have the greater voltage drop across it?

6. A certain circuit has an applied E.M.F. of 15 volts connected to a 5 and a 10-ohm resistor in series. What is the voltage drop across the 10-ohm resistor? What is the voltage drop across the 5-ohm resistor?

7. A series circuit consists of two resistors with a given voltage and current. Will the current increase or decrease if an additional resistor is added in series?

8. Is the voltage across parallel resistances equal?

9. State the rule for the total current in a parallel circuit.

10. Is the total resistance of a circuit increased or decreased as equipment is added in parallel?

11. Complete the circuit of Figure 6-38 so as to have the lamp and the coil in parallel and across the battery.

FIG 6-38

12. What is the total resistance of a circuit that has a 20-ohm lamp and a 40-ohm relay in parallel?

13. Find the total current in the parallel circuit of Figure 6-39.

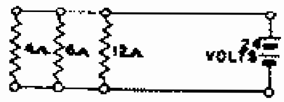


FIG. 6-39

14. Does the current returning to the source of E.M.F. always equal the current leaving the source?

15. How is the product and sum method applied to a circuit containing four resistors in parallel?

16. What is a series-parallel circuit?

17. Does the current have the same value in all parts of a parallel circuit?

18. Is the current the same in all parts of a series circuit?

19. What determines whether connecting a parallel path to a part of a circuit will decrease the flow through that part?

20. If key 1 is closed in Figure 6-40 through which lamps will current flow? Suppose that there was an open at X, through which lamps will current flow when key 1 is closed? CAUTION: Trace entire circuit carefully before attempting to answer.

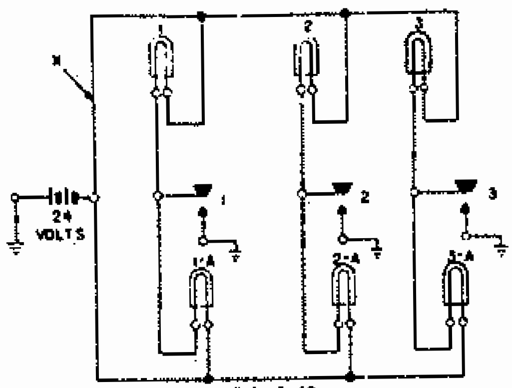


FIG 6-40

21. Why doesn't the portable lamp light in Figure 6-41? What can be used in place of the lamp for locating short circuits?

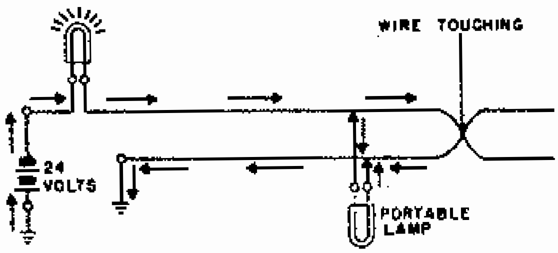


FIG. 6-41

22. If we knew the resistance per foot of cable conductor how could we use a Wheatstone Bridge to determine the length of a section of the cable?

23. Explain Kirchoff's voltage law.

24. Explain Kirchoff's amperage law.

25. Find the values listed below for the circuit of Figure 6-42.

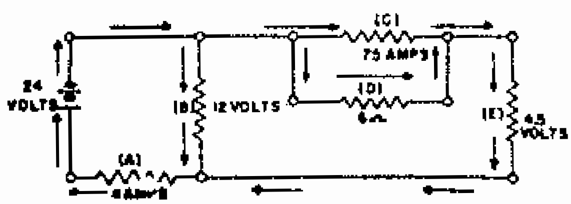


FIG 6-42

Voltage drop across (A)____
Resistance of (A)____
Voltage drop across (C)____
Voltage drop across (D)____
Resistance of (C)____
Current through (D)____
Current through (E)____
Resistance of (E)____
Current through (B)____
Resistance of (B)____

26. Find the values listed below for the circuit of Figure 6-43.

Voltage drop across (A)____
Resistance of (A)____
Voltage drop across (C)____
Voltage drop across (D)____
Resistance of (C)____
Current through (D)____
Current through (E)____
Resistance of (E)____
Current through (B)____
Resistance of (B)____

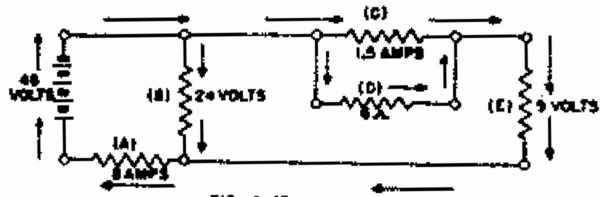


FIG 6-43

27. Find the values listed below for the circuit of Figure 6-44.

Voltage drop across (A)____
Resistance of (A)____
Voltage drop across (C)____
Voltage drop across (D)____
Resistance of (C)____
Current through (D)____
Resistance of (E)____
Current through (B)____
Resistance of (B)____

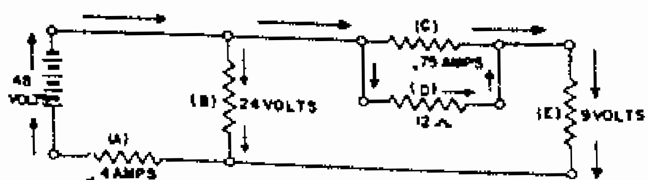


FIG 6-44

28. Find the values listed below for the circuit of Figure 6-45.

Current through (A) _______
Voltage drop across (A) _______
Voltage drop across (C) _______
Resistance of (C) _______
Voltage drop across (F) _______
Voltage drop across (G) _______
Resistance of (F) _______
Current through (G) _______
Current through (H) _______
Resistance of (H) _______
Current through (D) _______
Resistance of (D) _______
Voltage drop of (E) _______
Resistance of (E) _______
Current through (B) _______
Resistance of (B) _______

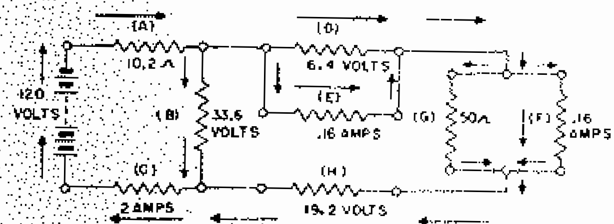


FIG 6-45

CHAPTER VII

POWER IN D.C. CIRCUITS

1. GENERAL

1.01 Power is an important factor in every day life, and in the communication field. An understanding of the fundamental physical laws of energy, and the following discussion of force, work, energy and power should be helpful to the student in solving problems in electrical power.

2. ENERGY

2.01 Energy is the capacity for doing work. Energy is not made or destroyed, but exists in one form or another as a constant amount for the whole universe. This is a fundamental law known as the Law of conservation of energy. Do not confuse this pure physical fact with the practical fact that great quantities of energy are converted daily into forms no longer available to man and are, therefore, lost for practical purposes. The expression "energy is expended or dissipated", is commonly used, and for practical purposes, is often true. Some common forms of energy are heat energy, electrical energy, mechanical energy and light energy.

2.02 Energy can be readily converted from one form to another. This is the law of co-relation of energy. An example illustrating this law is the electrical power plant. First, the chemical energy of the fuel becomes heat energy, which the boiler and turbine convert into mechanical energy. The generator then transforms this mechanical energy into electrical energy. In the form of electricity, the energy can be distributed over large areas for the convenience of man. Electrical energy is converted to heat energy by the electric iron, to mechanical energy by the motor, and to light and heat energy by the incandescent lamp. These are only a few examples of the transformation of energy in every day life.

3. FORCE

3.01 Force is that which tends to produce motion, a change of motion or change in shape of matter. Force is "push" or "pull". If a person pushes against a box, it may or may not move, depending upon the amount of muscular force exerted. If this "push" were exerted against a heavy stone wall, the wall would not move, yet force would be exerted. An example of electrical force is the dry cell. With no circuit connected to the terminals, there is an electromotive force of 1.5 volts between the terminals. This force is insufficient to overcome the resistance of the air between the terminals, therefore, no motion of electricity results. If a flashlight bulb is connected between the terminals, a current will flow through the electrical resistance of the filament. This motion of electricity is due to electrical force.

4. WORK

4.01 When a force overcomes a resistance and causes motion, work is done. Regardless of the force exerted, if no motion results there is no work done. The operation of a pile driver illustrates mechanical work. When the weight of the driving hammer is lifted against the force of gravity, work is done. This work stores energy in the weight, and while the weight is suspended, ready to drop, it possesses energy. The weight while suspended is exerting a force, but is doing no work.

4.02 The amount of work done is measured by the product of the force exerted times the distance the body moves. The unit of work is called the foot-pound. The work done in raising a weight of 1 pound a distance of 1 foot, against the force of gravity, is 1 foot-pound. Raising ten pounds ten feet would be 10 pounds x 10 feet or 100 foot-pounds.

4.03 Force performs work only when exerted through a distance, i.e., in overcoming a resistance. It makes no difference how long a time is required to do work, as long as the work is done. All work, whether chemical, mechanical, thermal or electrical can be expressed in foot-pounds. Work is independent of time, and whether the work is accomplished in one hour or one year, the amount of work is not changed.

5. POWER

5.01 Power is the rate at which work is done. To distinguish between work and power the pile driver is again used as an example. It is necessary to expend considerable energy on the pile to drive it even a short distance. The machine requires considerable work over a period of time to raise the weight. Suppose the machine was designed to raise the weight in ten seconds; and then it became necessary to change the machine so that the weight could be raised in five seconds. It would require twice as much power to raise the weight in five seconds.

5.02 Power is work divided by time. The unit of electrical work is the joule, and the unit of electrical power is the watt. 746 watts are equivalent to one mechanical horsepower. A joule is the energy expended in one second by an electric current of one ampere in a resistance of one ohm. One joule is the amount of work required to lift a weight of one pound about 8.85 inches.

5.03 The discussion of power and work may be summarized as follows:

a. Energy is the capacity to do work. Work is force acting through a distance. Power is the rate of doing work.

b. Energy cannot be destroyed, but can readily be transformed from one form to another.

c. The time used in performing work is the important factor in power.

6. WATT

6.01 The watt is the unit of electrical power, and is equivalent to 1 ampere of current at a pressure (e.m.f.) of 1 volt. Watts = volts x amperes, or d-c power = IE. By the use of this formula, the power consumed by an electrical device can be determined, if the current and voltage are known. For example, consider the motor in Figure 7-I.

To find the power, substitute the readings of the voltmeter and ammeter in the equation.

$I = 5$ and $E = 110$, therefore, $P = IE = 5 \times 110 = 550$ watts. A wattmeter would be used if available, because it reads directly in watts.

7. POWER LOSSES

7.01 The most common loss of power in electrical work is that due to the heat developed when current is flowing through a resistance. This heat is usually dissipated into the air, and lost for useful purposes, except when the resistance is used for heating. Examples of this use of heating are: electric ovens, soldering irons, and filament of vacuum tubes. Since all conductors have some resistance, transmission lines and circuits should be designed to minimize

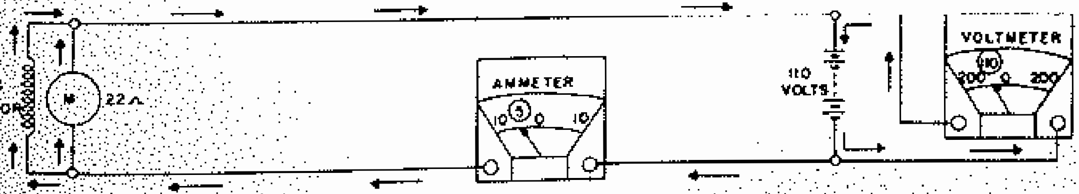


FIG 7-I

these losses. An example of equipment where great losses are tolerated to accomplish a given purpose is a home radio receiver. The receiver may consume more than 100 watts of electrical power; yet more than 3 watts of sound power from the speaker would be intolerable. Most of the loss is in heat energy, and it is for this reason that radio sets are well ventilated. Electric motors have losses due to friction and resistance of windings. Therefore, the mechanical output can never equal the electrical input. The output of any power consuming device, divided by the input, and multiplied by 100, will give its power efficiency. No machine can be 100% efficient.

8. RESISTANCE LOSSES

8.01 Resistance losses are an important consideration in communication work. The resistance used must be capable of radiating the heat generated without becoming hot enough to burn insulation or start fires. It is for this reason that resistors are usually rated in watts as well as ohms. This wattage rating indicates the safe wattage in heat that the resistor will radiate in free air without becoming damaged by heat. Resistors are often enclosed and may cause trouble in other parts of the equipment, due to poor radiation of heat.

8.02 The power equation, P=IE, can be readily modified by Ohm's law to allow calculation of power losses due to resistance. Substituting for E, its equivalents IR, the power equation becomes, $P=I^2R$. Substituting for I, its equivalent, $\frac{E}{R}$, the power equation becomes, $P=\frac{E^2}{R}$. These three power equations are commonly used. Electricians often refer to the "I^2R" losses of a circuit, which is a short way of saying, "The power lost in the circuit due to current flowing through the resistance."

8.03 An example of a practical use of the equation $P=I^2R$ is as follows: in Figure 7-2 the switchboard lamps are drawing 2 amperes and the total load resistance is 10 ohms. It is desired to determine the power loss in the load.

$$P = I^2R$$
$$I = 2 \text{ amperes}$$
$$I^2 = 4$$
$$R = 10 \text{ ohms}$$

Therefore $P = 4 \times 10 = 40$ watts.

8.04 An example of the practical use of the equation, $P=\frac{E^2}{R}$, is as follows: in Figure 7-3, a 20 ohm resistor is required to reduce the 12-volt battery voltage to 6 volts for lighting a 6-volt radio tube. It is desired to determine the wattage rating required of the resistor.

$$E = 6 \text{ volts}, \ E^2 = 36, \ R=20 \text{ ohms}$$

$$P = \frac{E^2}{R}$$

$$P = \frac{E^2}{R} = \frac{36}{20} = 1.8 \text{ watts}$$

In this example any standard size of resistor rated at greater than 1.8 watts could be used safely. This equation is commonly used in practice, because all that is required is a voltmeter reading across a resistor to determine how much power is being dissipated in the resistor.

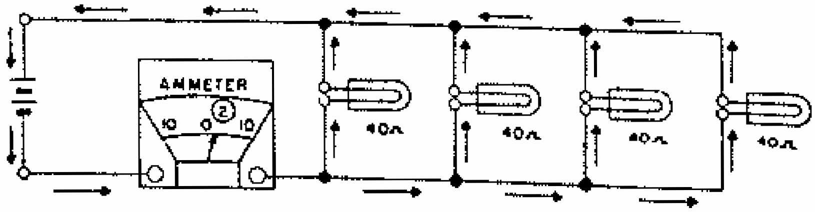


FIG 7-2

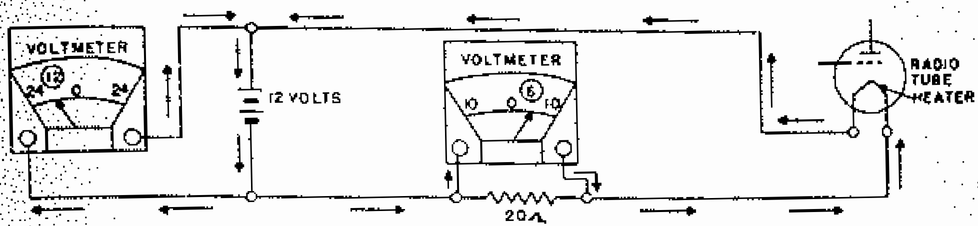


FIG 7-3

8.05 In order to determine the true amount of energy consumed, we must know not only the rate of doing work, i.e., the power, but also the length of time the power was used. Compare this to a motorist driving on a highway. If he knows his rate of travel (miles per hour) and the length of time he was been traveling (hours), he can compute the distance he has traveled.

It is common practice to purchase electrical energy by watt-hours, or kilowatt-hours (thousands of watt-hours). A 100-watt lamp requires 100 watts of power for proper operation, and consumes 100 watt-hours of energy in one hour. In terms of kilowatt-hours, the lamp uses $\frac{100}{1000} = 0.1$ kwh in one hour, or 1 kwh for 10 hours of operation.

9. A FORMULA WHEEL

9.01 By the use of Ohm's Law equations and the power equations, we can get 12 equations as shown in Figure 7-4.

9.02 An example of the practical use of the equation $I = \frac{P}{E}$ is as follows: in Figure 7-5 the motor is consuming 550 watts of power and the voltage is 110. It is desired to determine the current flow. No ammeter is available.

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

E = 110 volts
P = 550 watts

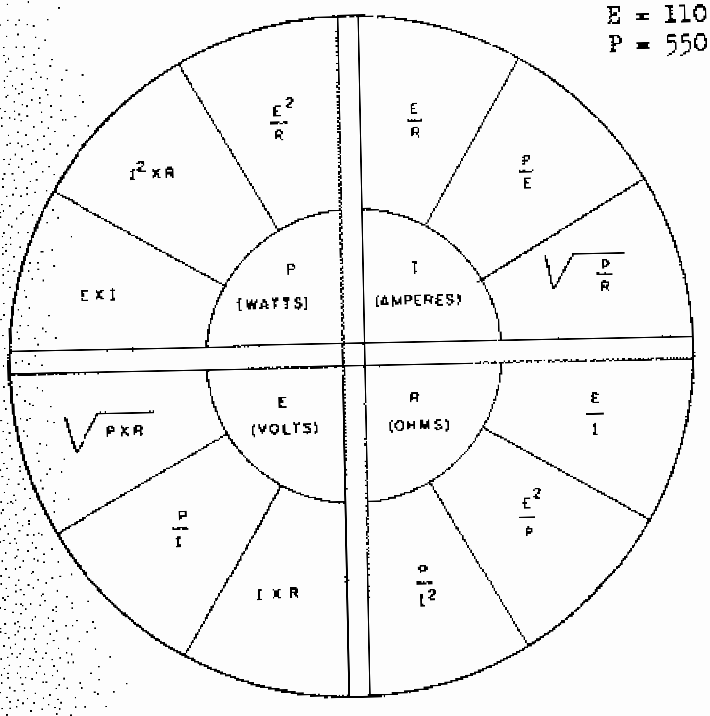


FIG. 7-4

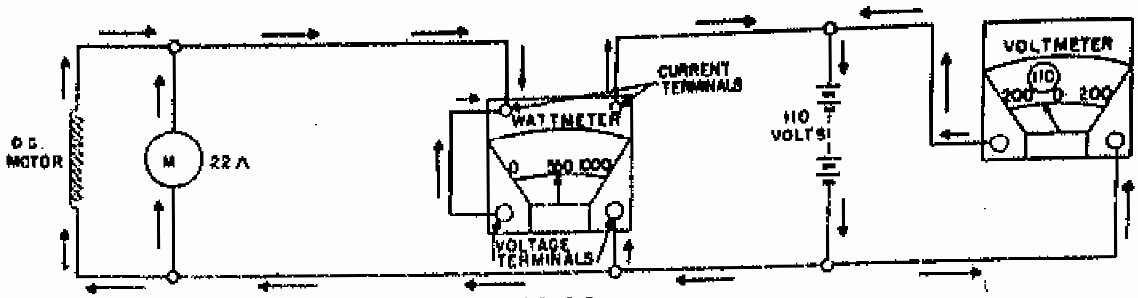


FIG. 7-5

Therefore $I = \frac{550}{110} = 5$ amperes

9.03 An example of the practical use of the equation $I = \sqrt{\frac{P}{R}}$ is as follows: in figure 7-5 the motor and its resistance is 22 ohms. It is desired to determine the current flow. No ammeter is available.

$$I = \sqrt{\frac{P}{R}}$$

P = 550 watts
R = 22 ohms

Therefore $I = \sqrt{\frac{550}{22}} = \sqrt{25} = 5$ amperes

9.04 An example of the practical use of the equation $R = \frac{E^2}{P}$ is as follows; in figure 7-5 the motor is consuming 550 watts of power and the voltage is 110. It is desired to determine the resistance of the motor. The resistance is not known.

$$R = \frac{E^2}{P}$$

P = 550 watts
E = 110 volts

$E^2 = 12100$

$$R = \frac{12100}{550} = 22 \text{ ohms.}$$

9.05 An example of the practical use of the equation $R = \frac{P}{I^2}$ is as follows: in figure 7-6 the motor is consuming 550 watts of power and the current is 5 amperes. It is desired to determine the resistance of the motor. The resistance is not known

$$R = \frac{P}{I^2}$$

P = 550 watts.
I = 5 amperes.

$I^2 = 25$

$$R = \frac{550}{25} = 22 \text{ ohms.}$$

9.06 If the voltage of the circuit in figure 7-6 were not known the equation $E = \frac{P}{I}$ can be used and the solution is as follows:

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

P = 550 watts.
I = 5 amperes.

Therefore $E = \frac{550}{5} = 110$ volts.

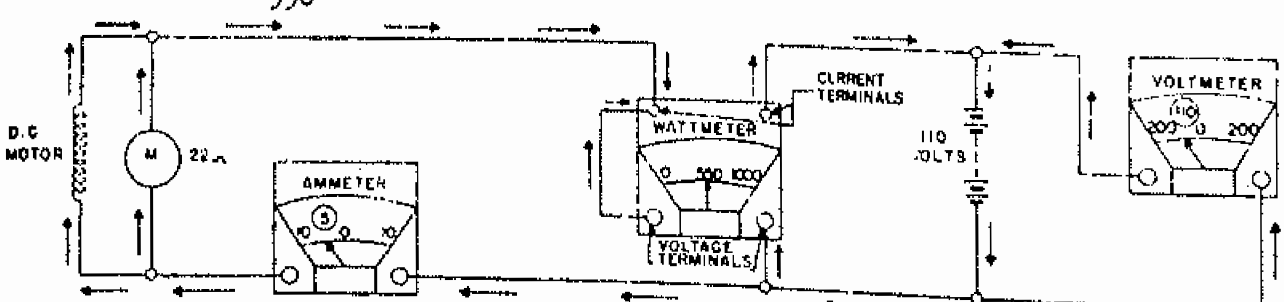


FIG 7-6

9.07 If the voltage of the circuit in figure 7-6 were not known the equation $E = \sqrt{P \times R}$ also could be used and the solution is as follows:

$$E = \sqrt{P \times R}$$

P = 550 watts.
R = 22 ohms.

Therefore $E = \sqrt{550 \times 22} = \sqrt{12100}$ = 110 volts.

10. SUMMARY

a. The watt is the electrical unit of power, and is equal to volts times amperes.

b. Heat is a power loss, and is sometimes referred to as I^2R loss.

c. The output of any machine can never be equal to the input to the machine.

d. Efficiency is equal to the output of a machine divided by the input to the machine times 100.

e. The watt rating of a resistor should never be exceeded. Never allow enough current to flow through a resistor so that the current squared times the resistance will exceed the watt rating resistor.

f. Electrical energy is purchased in terms of watt-hours or kilowatt-hours.

11. QUESTIONS

1. Can energy be destroyed?

2. What is the mechanical unit of work?

3. What is the electrical unit of work?

4. Can force be exerted without work being accomplished?

5. Is one kilowatt greater or less than one horsepower?

6. What is the unit of electrical power?

7. Can the mechanical output of a power consuming device ever equal the electrical input?

8. Why are resistors rated in watts as well as ohms?

9. Can the power consumed in a known resistance be determined if the voltage drop across the resistance is known?

10. What equation is used to determine the power lost in a known resistance when the current flowing through the resistance is known?

11. Give the expression for power in terms of work.

12. What becomes of the energy expended in a resistance?

CHAPTER VIII

PROTECTORS AND FUSES

1. PROTECTOR BLOCKS AND HEAT COILS

1.01 Practically every telephone circuit in the central office must be equipped with some form of protection which is sufficiently sensitive to operate before any damage to the equipment is done, but is not too sensitive to cause an unnecessary number of service interruptions. For the protection of the inside equipment, telephone lines enter the central office through protectors mounted on the main frame. These protectors consist of a protector mounting equipped with protector blocks and heat coils.

1.02 A diagrammatic view of such a protector unit with protector blocks and heat coils is shown in Figure 8-1. The protector blocks on each side of the line, as shown in this figure, consist of a plain carbon block and a porcelain block. A small carbon block is mounted in the center of the porcelain block by means of a fusible cement. When held in the protector, the plain carbon block and the carbon insert of the porcelain block are separated by a gap of approximately .003". Any lightning or other high voltage discharge will jump across this small gap between the two carbon blocks and follow the framework of the protectors to ground. Sparking will cause the fusible cement in the porcelain block to melt, thus permitting the small carbon insert to make direct and permanent contact with the larger block and ground.

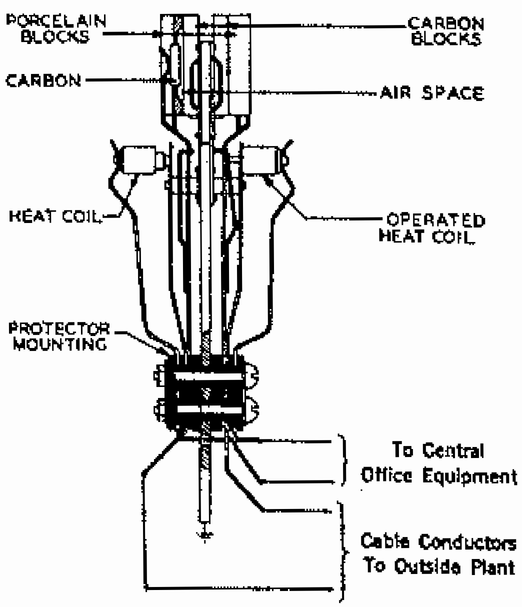


FIG. 8-1

1.03 The two carbon blocks in Figure 8-2 are separated by an air gap of a few thousandths of an inch. The voltmeter indicates that the highest ordinary telephone voltage does not cause current to flow across the gap. However, if a much greater potential difference is applied, as in Figure 8-3 the current arcs across the air gap.

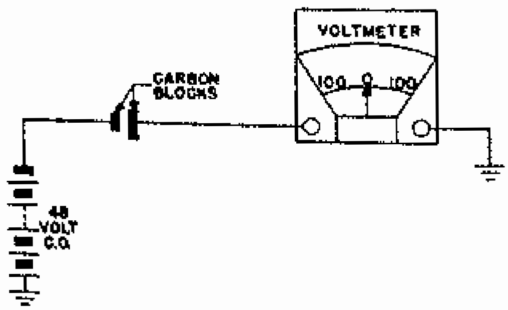


FIG. 8-2

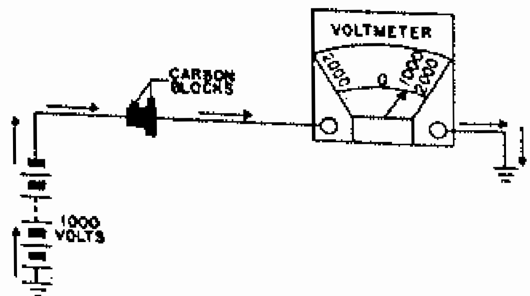


FIG. 8-3

This device is known as the carbon block protector, and is used to protect telephone equipment from lightning discharges, and from foreign high potential sources, such as high tension light circuits and street car feeders.

1.04 The heat coils associated with the protector are for protection against damage which may be caused by a subscribers line coming in contact with a power line. A 76 type heat coil, shown in Figure 8-4, consists

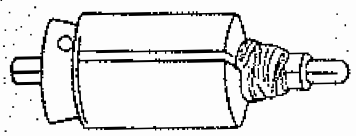
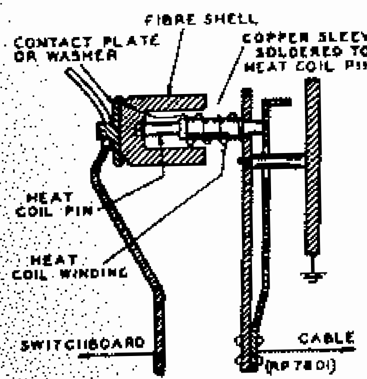


FIG. 8-4 76 TYPE HEAT COIL

essentially of a winding of fine alloy wire on a copper sleeve which is soldered to a pin. When an excessive electric current passes through the winding of the coil, the soldered joint inside the coil will melt. Upon melting, the pressure of the protector spring on the head of the coil causes the pin to slip through the copper sleeve. An auxiliary contact spring resting against the free end of the heat coil pin is thereby brought into contact with the frame thus grounding the line as shown on the right hand side of Figure 8-1. A cross-sectional view of a heat coil mounted in a protector is shown in Figure 8-5.



CROSS-SECTION OF HEAT COIL

FIG. 8-5

2. HEATING EFFECT OF CURRENT

2.01 The section of wire wrapped around the thermometer in Figure 8-6 has appreciable resistance.

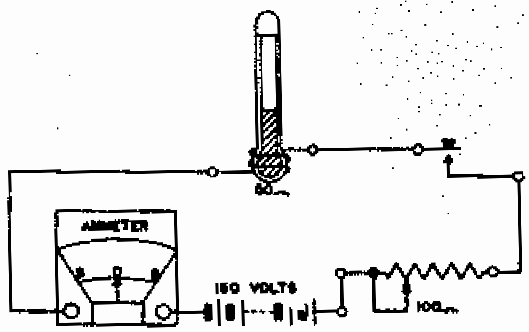


FIG. 8-6

When the circuit is closed, the reading of the thermometer increases showing that the current flowing in the wire produces heat (Figure 8-7). The cur-

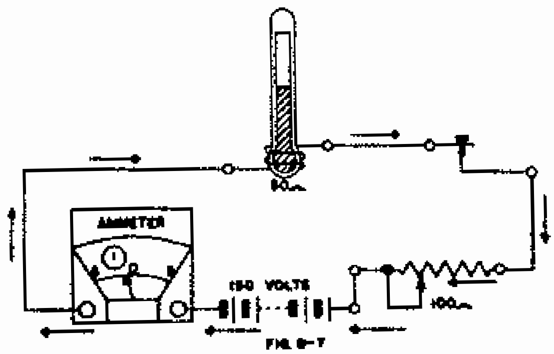


FIG. 8-7

rent flow has been increased in Figure 8-8 and the temperature further increases, i.e., the temperature produced in a conductor is proportional to the current flow through it. If

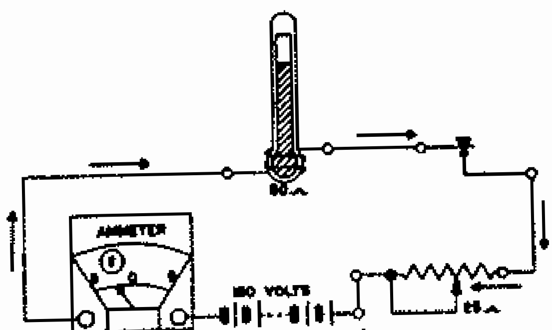


FIG. 8-8

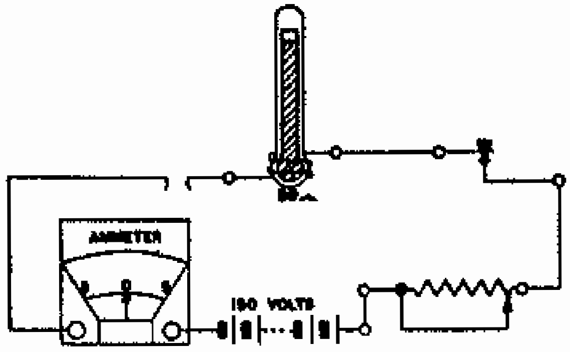


FIG 8-9

the current is great enough it will burn in two or burn the insulation about it if the insulating material is combustible (Figure 8-9).

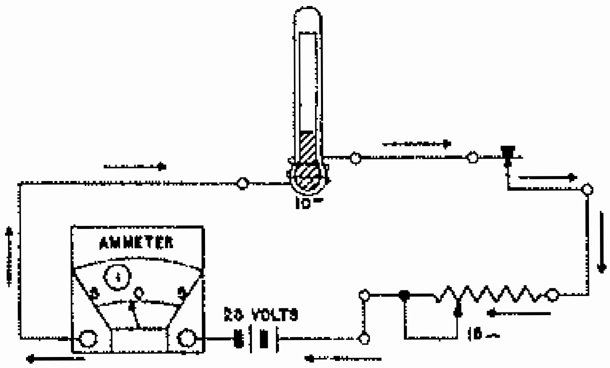


FIG 8-10

2.02 The section of wire wrapped around the thermometer in Figure 8-11 has greater resistance per inch than the corresponding section in Figure 8-10. The fact that the thermometer indicates a greater temperature in Figure 8-11 demonstrates that for a given current flow the temperature produced in a wire is proportional to the resistance per unit length of the wire.

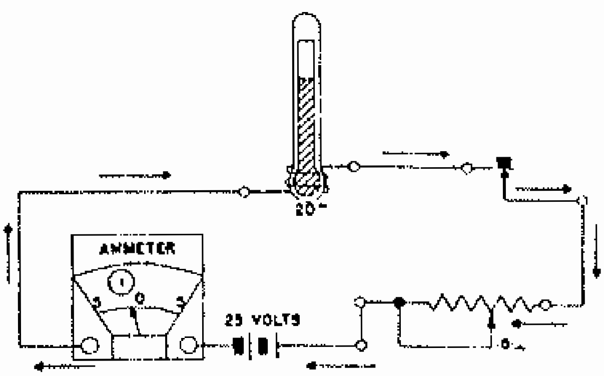


FIG 8-11

3. FUSES

3.01 A short section of fuse metal which will melt at a low temperature is included in the circuit shown in Figure 8-12. If enough current

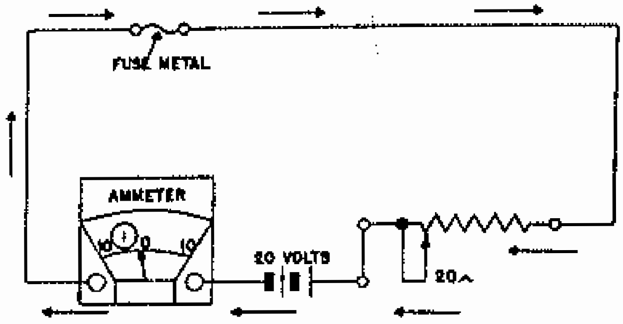


FIG 8-12

flows to cause undue heating in the circuit, the fuse wire melts and opens the circuit (Figure 8-13). Thus, the rest of the circuit is protected against overheating. In order to restore the circuit, the fuse metal must be replaced. Such a protective device is known as a <u>Fuse</u>. When the fuse metal melts we say that the fuse "blows".

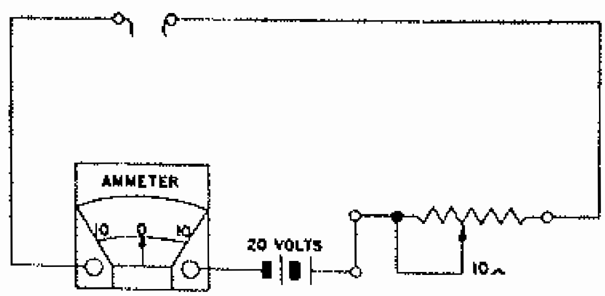


FIG 8-13

The operation of a fuse is based upon the melting of an alloy at a low temperature. A fuse is usually constructed with a small wire or ribbon of the alloy, either encased in a fireproof container or arranged for mounting on fireproof panels.

3.02 Fuses are made in various types and current carrying capacities to meet various needs. A fuse in any circuit must be capable of carrying the greatest current required in the normal operation of the circuit, but must blow on a current less than enough to do damage to any part of the circuit. Some fuses will blow almost instantly if their rated capacity is exceeded; while others are made so that they will carry a considerable overload for a short time, but will blow if their rated capacity is at all exceeded for a considerable time.

3.03 Fuses are used extensively for the protection of local circuits in the telephone central office. Figure 8-14 shows the 35 type fuse which is commonly used for this service. This fuse is of the indicator alarm type and is generally referred to as a "Grasshopper" fuse. It consists of a thin strip of insulation with slotted tinned terminals at each end. The fuse wire is held between a small coil spring on top and a leaf spring on the bottom.

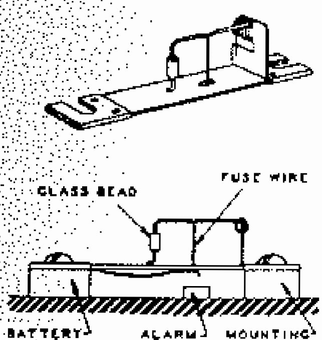


FIG. 8-14

When the 35 type fuse blows, the springs are released and take the position shown in Figure 8-15. The released leaf spring underneath the fuse now makes contact with a contact bar on the fuse board, thereby closing an alarm circuit which notifies the maintenance man by the ringing of a bell that a fuse has blown. In order to facilitate the location of a blown fuse on the fuse board, a glass bead is placed at the end of the coil spring. When the fuse blows, the beaded end projects beyond the line of the other fuses in such a way as to be readily located.

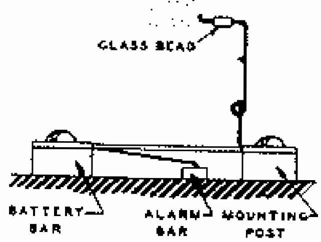


FIG. 8-15

Figure 8-16 shows a typical circuit associated with the 35 type fuse. If sufficient current flows through the fuse to melt the fuse wire the glass bead moves outward indicating that the fuse has operated and the leaf spring makes contact with the audible alarm circuit (Figure 8-17).

The 35 type fuses are made in various capacities up to five amperes. In order to facilitate selection, different colored beads are used for each capacity.

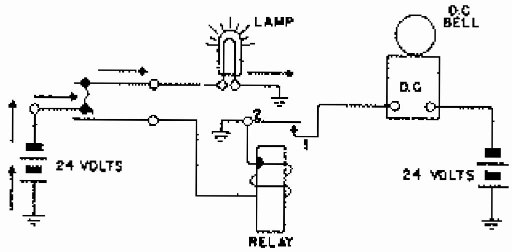


FIG. 8-16

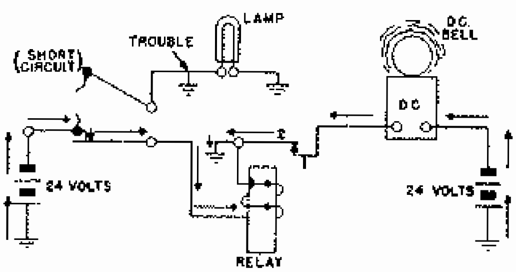


FIG 8-17

For use in circuits carrying over 90 volts, 35 type fuses are provided with a glass or porcelain tube over the fuse wire. This prevents the flash which occurs when the fuse operates from operating adjacently mounted fuses in other circuits.

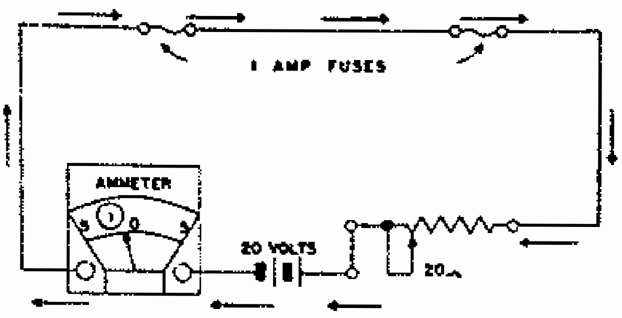


FIG. 8-18

3.04 Two fuses, each capable of carrying one ampere, are connected in series in Figure 8-18. If the current exceeds one ampere one or the other of the fuses blows and opens the circuit, (Figure 8-19). (Occasionally both fuses will blow at the same time.) Two fuses in series are capable of standing the same amount of current as either one alone.

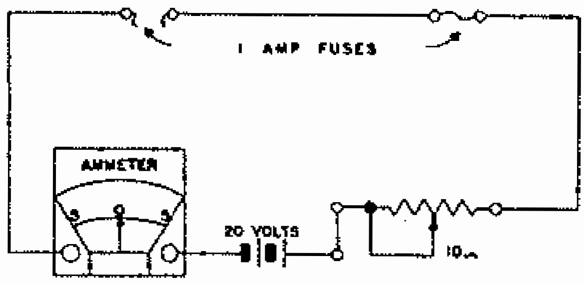


FIG. 8-19

3.05 In Figure 8-20 two one ampere fuses are connected in parallel. The ammeter indicates that nearly two amperes are flowing in the circuit. That is, each fuse is carrying one ampere. If the current is further increased, the weaker fuse will blow.

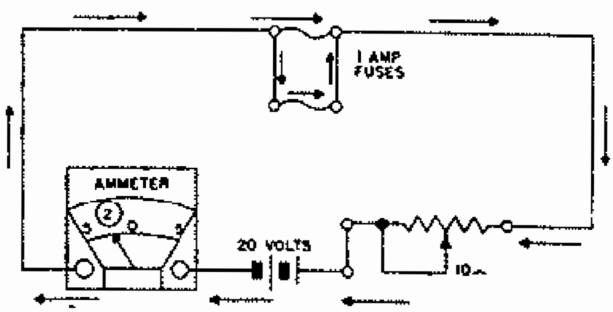


FIG. 8-20

This means that all of the current must now go through the other fuse so that it will blow at once, (Figure 8-21).

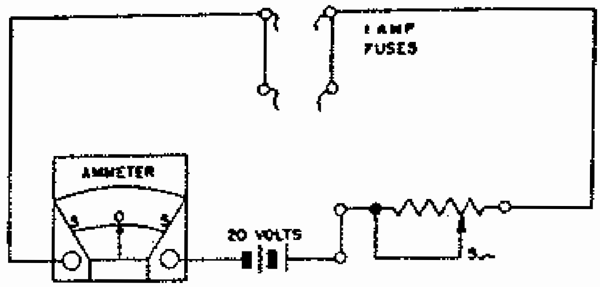


FIG. 8-21

The principle is that the current carrying capacity of fuses in parallel is equal to the sum of the capacities of the individual fuses. However, if the current becomes great enough to cause one fuse to blow, the current which that fuse was carrying is divided among the other fuses.

This principle is used to provide alarm operation when high capacity fuses operate. The high capacity fuse has an indicator alarm fuse of low capacity connected in parallel with it.

4. QUESTIONS

1. What are the component parts of a protector?

2. What is the function of a heat coil and how does it operate?

3. What happens when a protector block is subjected to prolonged sparking?

4. What kind of protection is used for local telephone circuits?

5. Why are 35 type fuses equipped with different colored glass beads?

6. What would happen if the 100 ampere fuse in Figure 8-22 blew?

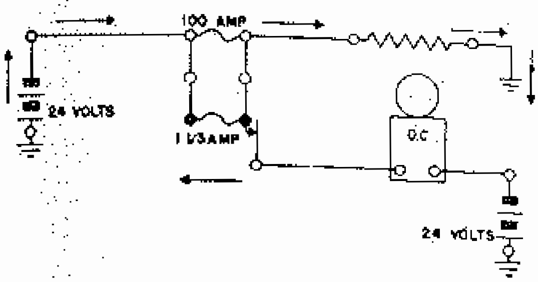


FIG. 8-22

7. Will point A of the rheostat in Figure 8-23 be hotter when the arm is to the left or when it is to the right? Why?

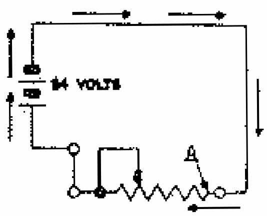


FIG. 8-23

8. Would it be safer to have the switch open or in position 1 while changing fuse No. 1 in Figure 8-24? Why?

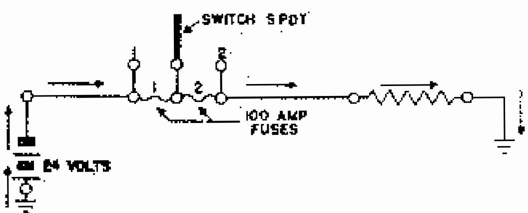


FIG. 8-24

9. Will a current which is less than a fuse is rated to carry blow the fuse if it continues for a long time?

10. Will a heat coil carry a comparatively large current for a very short time? May a smaller current operate the coil if it continues for a long time?

CHAPTER IX

MAGNETISM

1. NATURAL MAGNETS

1.01 The ancient Greeks discovered that a certain kind of rock would attract or pick up bits of iron. They attributed this quality to supernatural causes and made no use of it except to create stories about it. This rock is one of the iron ores which is often called magnetite.

1.02 Centuries later, the Orientals learned that a piece of the magnetite when mounted in a horizontal plane and allowed to rotate would turn so that one end always pointed towards the north. The Europeans learned of this discovery and used it as an aid to navigation. Because of this property the ore became known as a leading stone or lodestone. Pieces of ore which have this magnetic property are called natural magnets.

2. ARTIFICIAL MAGNETS

2.01 The Europeans soon learned that they could use this natural magnetic ore to make magnets out of iron and steel. Such magnets are called artificial magnets. Artificial magnets can be made by stroking a steel bar with a piece of lodestone.

2.02 It has been found that the best magnets are made of steel. Even though iron is more easily magnetized than steel, it does not retain its magnetism so well. Since steel retains its magnetism better than iron, it is said to have greater retentivity than iron. Developments in the manufacture of steel alloys have produced steels of exceedingly high retentivity. Cobalt-steel and "alnico" are examples of this development.

3. POLES

3.01 It is well known that ordinary bar or horsehoe magnets, such as those shown in Figure 9-1, will attract pieces of iron or steel, such as nails or screws. Such magnets are known as permanent magnets, as they retain their magnetism indefinitely.

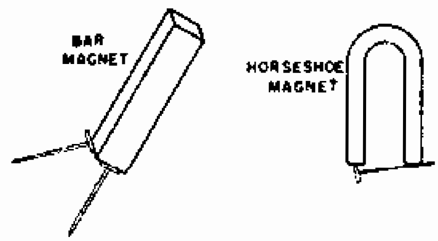


FIG 9-1

3.02 If a bar magnet is suspended so that it can turn freely in a horizontal plane, it will finally come to rest in a north and south position, (Figure 9-2). If this experiment is repeated, it will be found that the same end will always point north. This end is called the north pole of the magnet, and the other end the south pole. The needle of an ordinary compass is simply a small bar magnet suspended so that it is free to rotate in a horizontal plane.

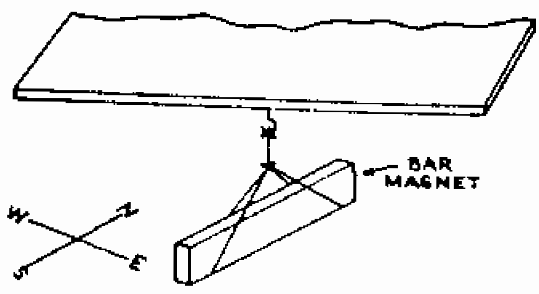


FIG 9-2

3.03 If the north pole of one magnet is brought near to the south pole of another magnet, they tend to pull themselves together, (Figure 9-3). After they come into contact they stick together, (Figure 9-4). That is, unlike poles attract each other.

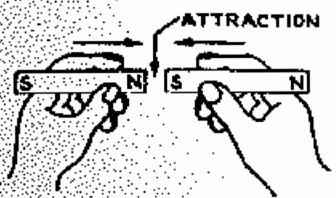


FIG. 9-3

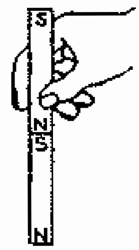


FIG. 9-4

3.04 On the other hand, if the two north poles or the two south poles are brought near each other they tend to push each other apart, (Figure 9-5). That is, like poles repel each other.

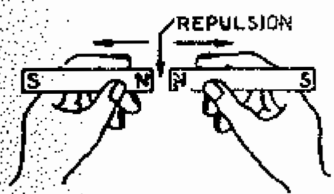


FIG. 9-5

4. MAGNETIC FORCE

4.01 If a bar of soft iron is brought near to either the north or the south pole of a magnet it will be attracted, (Figures 9-6 and 9-7). It may be shown that the end of the iron bar away from the magnet in Figure 9-6 is a north pole and that it becomes a south pole when the poles of the magnet are interchanged as in Figure 9-7. We say that the iron bar is magnetized by induction. If the free end of the bar is brought near some iron tacks, they will be attracted, (Figure 9-8). When the permanent magnet is withdrawn, however, the tacks will drop off; showing that the iron bar is a magnet only while it is being affected by the permanent magnet, (Figure 9-9).

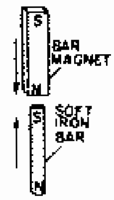


FIG 9-6

FIG 9-7

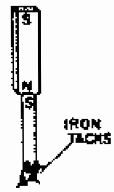


FIG 9-8

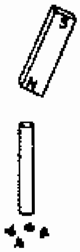


FIG 9-9

4.02 The spring balance in Figure 9-10 indicates how much force must be exerted in order to pull the magnet and the iron bar apart. The magnet in Figure 9-11 is the same except that it has been bent in the shape of a horseshoe. The balance indicates that the horseshoe magnet pulls the piece of iron much harder than the bar magnet.

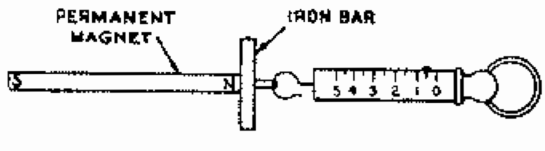


FIG 9-10

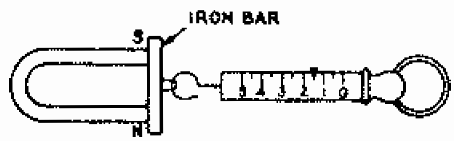


FIG. 9-11

4.03 Figure 9-12 shows a bar magnet pulling against a soft iron bar, which is called an armature, pivoted at one end. The spring balance indicates the strength of the pull. In Figure 9-13 a piece of soft iron has been placed between the opposite end of the magnet and a point near the pivot. The increased pull on the balance indicates that adding the iron in this manner produces an effect similar to bending the magnet into a horseshoe. The principle is that the

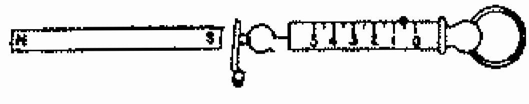


FIG 9-12

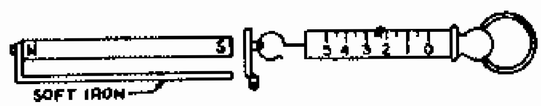


FIG. 9-13

more nearly a complete circuit of iron there is, the more effective the magnet. This is further borne out by the fact that when the bar is allowed to move nearer to the end of the magnet, the pull is increased, (Figure 9-14).

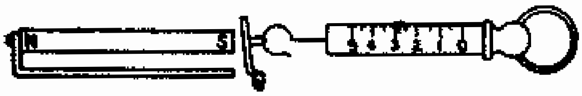


FIG 9-14

4.04 Since bits of iron may be lifted by a magnet, the magnet must exert a force upon the iron. This force acts at a distance. This fact may be observed by noting the action of a magnet on iron filings; the magnet causes filings to move even though the magnet and filings are not in contact. The force acts through almost any substance; which can be shown by moving a magnet beneath a glass plate on which is sprinkled iron filings. As the magnet is moved, movement of the filings is perceptible. Next, it can be shown that the force is mutual, for a magnet can be attracted to a firmly held piece of iron just as strongly as the iron is attracted to the magnet.

5. MAGNETIC FIELD

5.01 Since a magnetic pole acts at a distance upon other poles, there must be a space around every magnetic pole in which the magnetic force becomes evident as soon as another magnetic material is placed anywhere within that space. This space about a magnet in which the magnetic force is evident, is called the field of the magnet or the magnetic field.

5.02 A magnetic field is in one sense like a stream of water. The water exerts no pressure until an object is placed in the stream, giving something against which it can push, yet the force is there only awaiting an object upon which to act.

5.03 A magnetic field may be considered as a force; a force has direction and so does a magnetic field. A magnetic pole placed in the field would move in the direction of the force. If it were a north pole it would move in one direction, and if it were a south pole it would move in the opposite direction. To find the direction of a field, the polarity of the pole placed in the field to indicate the direction, must be known. By convention, the positive direction of a magnetic field at any point is defined as the direction in which a free north pole, placed at that point, would tend to move.

5.04 The magnetic field at any point is simply the force with which a free north pole would be acted upon at that point. Therefore, since a compass needle is acted upon anywhere on the earth, there must be a magnetic field surrounding the earth, whose direction and intensity changes from point to point. This field is invisible but for many purposes it must be indicated. This representation is made by means of lines of force. If a free north pole is set down within a magnetic field and allowed to move, its direction of motion at each point is the direction of the field at that point. As the north pole is moved, it will trace a line of magnetic force from the north pole of the magnet to the south pole of the magnet, since it is repelled by the north pole and attracted by the south pole. A line of force may be defined as a line whose direction at every point through which it passes is the direction of the magnetic field at that point. Lines of force leave the magnet at the north pole and enter a magnet at the south pole, this being the conventional direction of the magnetic field. See Figure 9-15.

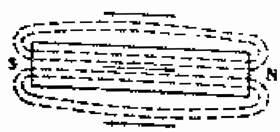


FIG 9-15

5.06 For purposes of illustration, 4-lines of force are shown in Figure 9-15, two on each side of the magnet. Many thousands of lines actually exist for any magnet. Notice that the lines of force do not cross.

5.07 Since the lines of force travel inside the magnet from south to north to complete their path, it can be said that the lines of force are continuous and can not be broken. This movement of the lines from south to north is within the magnet and therefore are not perceptible.

5.08 In Figure 9-15, there are 4-lines of force at each of the poles of the magnet, and only two lines of force on either side. As the lines of force represent the strength of the magnetic field it may be stated that the strength of the magnetic field is greatest at its poles. This can be proven experimentally.

6. RELUCTANCE

6.01 All magnets do not have the same strength, therefore the field of various magnets do not contain the same number of lines of force. The number of lines of force of a given magnet may be increased by decreasing the distance these lines of force must travel outside the magnet. When a line of force leaves the magnet at the north pole, it must travel through the air to reach the south pole because lines of force do not cross one another. Air offers resistance to the lines of force. This resistance to magnetic lines of force is called reluctance. In addition to air, other objects give a certain amount of reluctance to lines of force; for example, copper offers considerable reluctance. In order to reduce the distance that the lines of force of a magnut must travel outside a magnet, and to concentrate the field of the magnet, some magnets are bent in the shape of a horseshoe. See Figure 9-16.

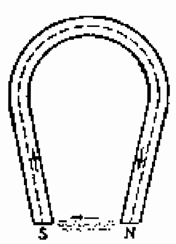


FIG. 9-16

6.02 Another method of concentrating the field of a magnet is to place a substance in the field that offers less reluctance to the magnetic lines of force than air, thus creating a stronger field. The substance most commonly used is soft iron. Figure 9-17 shows a horseshoe magnet with small blocks of soft iron placed against the inner surface of each pole.

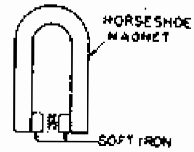


FIG. 9-17

These blocks, known as pole pieces, serve to conduct the magnetic lines and the result is a very intense magnetic field in the small air gap between the pole pieces. The soft iron lowers the reluctance of the field and allows a stronger field to be produced in the air gap thus creating a stronger force.

7. SHIELDING

7.01 Soft iron may also be used to protect an object from magnetic lines of force, by placing the object in the center of a circle formed by soft iron. Any magnetic lines of force, near this combination will take the path of least reluctance through the iron circle, therefore not disturbing the object. From this example it can be seen that soft iron may be used to distort a magnetic field. Any substance that offers less reluctance to the magnetic lines of force than air can be used for the same purpose.

8. MAGNETIC INDUCTION

8.01 If a magnet is dipped into iron filings, these filings will not only cling to the magnet, but will also cling to one another. We say that the filings have become magnets by induction. Such induced magnetism is in most cases only temporary; it vanishes when the inducing magnet is removed. When magnetism has been induced into a substance by the use of another magnet, and this substance retains some of the induced magnetism after the inducing magnet has been removed, this retained magnetism is called residual magnetism. The amount of residual magnetism remaining in a substance depends primarily upon three things; the composition of the substance (its retentivity), the strength of the inducing field, and the length of time the substance is in contact with the inducing magnet.

8.02 A method of making permanent magnet by induction is to stroke a retentive substance with a magnet, following the same direction of stroking each time. See Figure 9-18.

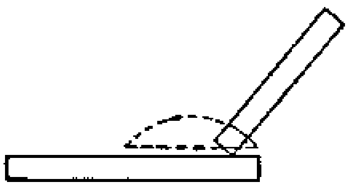
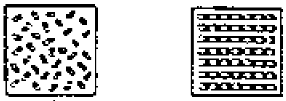


FIG. 9-18

8.03 This method of induction can be more easily understood if the substance is imagined to be composed of millions of molecules, each molecule in itself a tiny magnet. As the north pole of the inducing magnet is drawn over the substance, it attracts the south poles of these molecules and turns them so that they align themselves in one given direction, thus creating a magnet by adding the combined magnetic strength of the individual molecules. Figure 9-19 represents a substance before and after magnetizing.



(A) (B)

FIG. 9-19

9. PERMEABILITY

9.01 It has been shown that soft iron, when placed between two magnetic poles, will allow an additional number of lines of force to pass through a space formerly occupied by air. The ratio of the number of lines of force which pass through a given space when it is occupied by a substance, to the number of lines of force passing through that space when it is occupied by air, is called the permeability of the substance. For example, suppose a magnet would produce 100 lines of force through air, and would produce 1,000 lines of force when a soft iron bar was placed in the field. The permeability is represented by the symbol μ, (the Greek letter Mu).

9.02 For all substances except magnetic substances the permeability is approximately one. The permeability of magnetic substances is numerically always greater than one, and under certain conditions may be in the thousands.

10. APPLICATION

10.01 In telephone practice, it is often necessary to place two or more magnets together to obtain a field strong enough to produce the desired results. Such a combination is known as a compound magnet. An example of such a magnet is the generator in the local-battery telephone. This magnet employs from two to five magnets. In constructing such a magnet, all the north poles are placed together, and all the south poles are placed together, thus forcing the field across the air gap. Figure 9-20 represents the proper method of placing two magnets together to form a useful field. Figure 9-21 represents two magnets improperly placed to obtain a compound magnet.

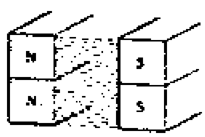


FIG. 9-20

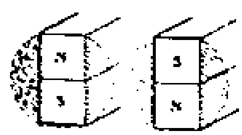


FIG. 9-21

10.02 A substance that has been magnetized, may be demagnetized by excessive vibration or heating. This fact may be explained by the molecular theory; striking a magnet with a hammer jars the molecules to move into a jumbled position. Thus, heating or excessive jarring of a magnet will weaken or even completely destroy it. Equipment containing permanent magnets should be handled with reasonable care to prevent demagnetizing, which causes errors in measuring instruments and unserviceability in many other types of equipment.

11. QUESTIONS

1. What are the two general types of permanent magnets?
2. What is the rule for attraction and repulsion of magnetic poles?
3. Which makes the better magnet, iron or steel? Why?
4. State the direction of the external magnetic field with relation to the two poles of the magnet.
5. In what direction do the lines of force travel inside the magnet?
6. Are lines of force continuous?
7. Do lines of force cross each other?
8. Is it possible to have a magnet with a single pole?
9. How are artifical magnets made?
10. What determines the amount of residual magnetism in a substance?
11. What is meant by the term permeability?
12. Do all magnetic substances have a greater permeability than air?
13. What is a compound magnet?
14. What is meant by the term retentivity?
15. Which metal has the greater retentivity, steel or iron?
16. What two methods may be used to demagnetize a magnet?
17. What two methods are used in practice to increase the strength of a magnet and concentrate the field?
18. Draw a magnet showing three complete lines of force and indicate by arrows the conventional direction of these lines.
19. How may equipment containing permanent magnets be damaged?
20. What is meant by the term reluctance?
21. How is magnetic shielding accomplished?

CHAPTER X

ELECTROMAGNETISM

1. LINES OF FORCE

1.01 Electromagnetism, in contrast to natural magnetism, is the magnetic field of force set up around a conductor by the passage of an electric current through it. Every electric current produces a magnetic field which, in case of a straight conductor, may be represented graphically as shown in Figure 10-1.

1.02 The lines of force about the wire are concentric circles. The intensity of the magnetic field varies inversely with the distance from the conductor and since the magnetic field is the result of the current flowing in the conductor, the strength of this field is proportional to the strength of the current flowing in the conductor. If the direction of the current through the wire is reversed the direction of the lines of force will also be reversed.

1.03 The presence of a magnetic field around a current-carrying conductor may be demonstrated easily by placing a freely suspended magnetic needle (a compass) near it. The needle will tend to place itself at right angles to the conductor and parallel with the lines of force. Since a magnetic field, by definition is the region in which a magnetic needle is acted upon by a force, it follows that the space surrounding the current-carrying conductor is a magnetic field.

1.04 In drawings and illustrations the direction of current flow and the direction of the magnetic field generally are shown. In Figure 10-1, for example, the direction of the electron current flow in the right hand drawing, is into the paper. In the left hand drawing the electron current is flowing out from the paper in the conductor. On both drawings the direction of the magnetic field is indicated by the arrows on the lines of force.

2. LEFT HAND RULE

2.01 After the discovery of the relationship between the current direction and the direction of the magnetic field caused by the current, a simple rule was set up to find the direction of the magnetic field when the direction of the current is known. This rule is known as the left hand rule for determining the direction of the magnetic field about a current-carrying conductor, and stated simply, is as follows: Grasp the conductor in the left hand with the thumb pointing in the direction of the current flow. The fingers will point in the direction of the magnetic field.

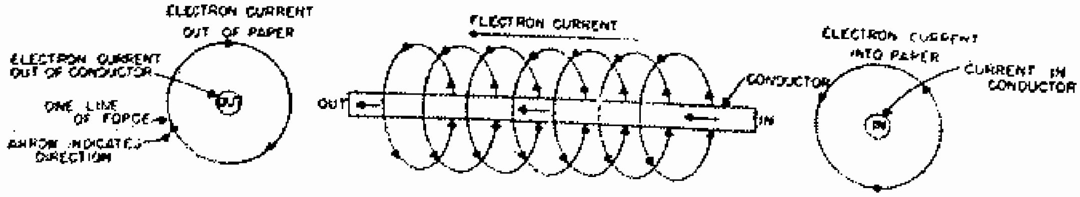


FIGURE 10-1

3. AMPERE TURNS

3.01 If the straight conductor shown in Figure 10-1 is bent into the shape of a 1-turn loop as shown in Figure 10-2, all of the lines of force which encircle the wire must enter the plane of the loop on one side and leave on the other.

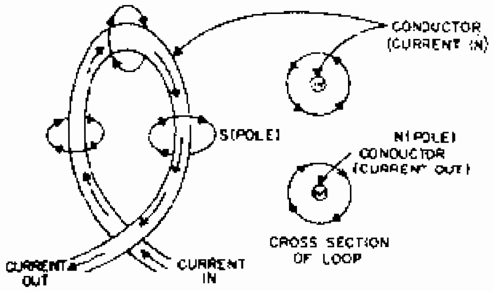


FIGURE 10-2

3.02 All the magnetic force, which in Figure 10-1 entered the paper beneath the conductor for its entire length, now is confined to the area within the loop. There is still the same number of lines of force produced by the length of conductor but when bent into the shape of a loop the force becomes concentrated within the loop.

3.03 If several turns are used and they are placed close together as shown in Figure 10-3, then the magnetic force produced by any one turn is in the same direction as that produced by any other turn and the magnetic force may be shown extending through the entire length of the coil.

3.04 These lines of force do not stop at the ends of the coil, but continue, external to the coil, and eventually bend around to enter the opposite end exactly as if the coil were a magnet having a north and south pole. All the lines of force originating within the coil, which pass one end, must eventually return to the other end, since any line of force must close.

3.05 If the turns of wire in a coil are close together, and are wound continously in the same direction around the core the combined magnetic field is essentially the sum of those produced by the individual turns. Such an arrangement of more than one turn, wound close together is called a coil. The magnetizing force set up by a coil or solenoid is known as the <u>magneto-motive force</u> and is directly proportional to the number of turns in the coil and the current flowing through it. The product of the turns and the current, when the current is in amperes is known as ampere-turns.

4. POLARITY OF A COIL

4.01 A coil carrying a current has a north pole and a south pole just the same as a 2-pole bar magnet, and its polarity may be found by applying the left hand rule for determining the polarity of a coil. The rule may be stated as follows: IF THE COIL IN FIGURE 10-3 IS GRIPPED IN THE LEFT HAND SO THAT THE FINGERS POINT IN THE DIRECTION OF THE FLOW OF ELECTRON CURRENT, AND THE THUMB IS EXTENDED AT RIGHT ANGLES TO THE FINGERS, THE THUMB WILL POINT TOWARD THE NORTH POLE. If the current is reversed the poles will reverse.

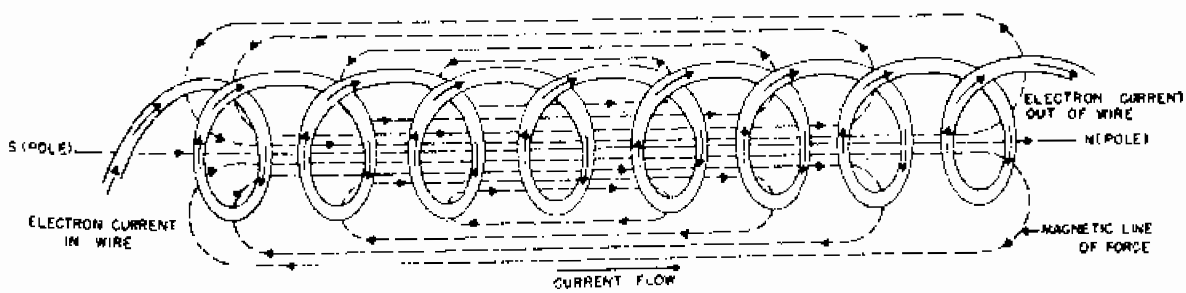


FIGURE 10-3

5. ELECTROMAGNETS

5.01 An electromagnet may be defined as an iron core surrounded by a coil of wire. The iron in the core is used to reduce the reluctance of the magnetic circuit, and to develop a greater flux (more lines of force) than could be developed if no core were used. This is true because the permeability of iron is approximately 2,000 times greater than air.

5.02 A piece of iron can be visualized as containing millions of tiny magnets which, unless otherwise influenced, lie in a haphazard fashion so that they neutralize each other and there is no resultant magnetic field surrounding it. If the iron is exposed to the influence of a magnetic field, the little magnets turn, similar to a compass needle, their north poles pointing in one direction and their south poles pointing in the opposite direction so that the fields are additive. The degree of magnetization depends upon how completely they can be "lined up". If the magnetizing force is weak, only a part of them will be swung into line, and a weak magnet results.

5.03 When the magnetizing force is removed, all of them do not return to their haphazard positions, so that the piece of iron or steel still has polarity. This remaining magnetism is called residual magnetism. Pure soft iron possesses this quality to only a slight degree, while very hard steel possesses it to a very high degree. In other words, a permanent magnet is one so hard that its particles do not readily swing back to their original positions once they have been influenced by a magnetic field. The tendency of a relay to hold up its armature after the circuit has been opened is caused by the residual magnetism in the core of its electromagnet. Therefore, relay cores are usually made of iron having very little retentivity (soft iron or alloys having high permeability and low retentivity).

5.04 The rule for determining the polarity of an electromagnet is the same as for a solenoid. It made no difference whether the wire is wound in one layer or in any number of layers; whether it is wound toward one end and then back over this layer toward the other end or whether all layers are wound in the same direction; as long as the current circulates continuously in the same direction around the core, the polarity of the magnet will be unchanged.

6. ELECTROMAGNET APPLICATIONS

6.01 Current is flowing through the coil of insulated wire in Figure 10-4. The north pole of the compass needle is attracted to the nearest end of the coil. If the other end of the coil is held near the compass, the south pole of the needle will be attracted, (figure 10-5).

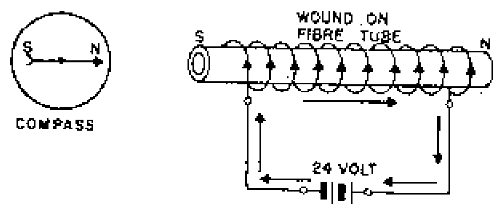


FIGURE 10-4

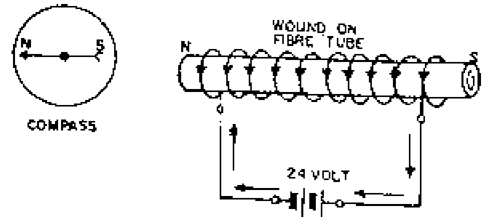


FIGURE 10-5

6.02 If the circuit were opened, the needle would no longer be affected. Thus, it is seen that a coil of wire acts as a magnet when current is flowing through it. Such a coil is known as an electromagnet.

6.03 If a core of soft iron is inserted the magnetic effect is greatly increased. In Figure 10-6 current is flowing through the coil and iron nails are clinging to the end of the core. When the circuit is broken, the nails fall off, (Figure 10-7).

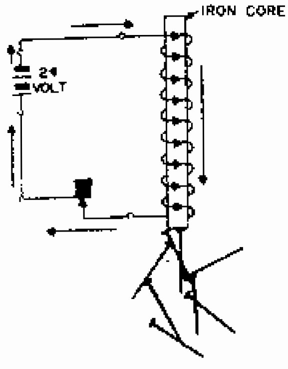


FIGURE 10-6

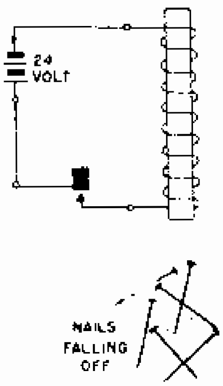


FIGURE 10-7

6.04 The core of the coil shown in Figure 10-8 is made of hard steel instead of soft iron. Not as many nails will cling to it as to the soft iron core, but when the circuit is broken, some of the nails fall off while the rest continue to cling, (Figure 10-9). It may, therefore, be seen that a soft iron electromagnet core is more efficient than a steel one, but that the steel one retains its magnetism after the current flow has ceased. Hard steel is used for making permanent magnets, and soft iron or permalloy are generally used for the cores of electromagnets. Permalloy is an alloy developed by the Bell Laboratories which consists of iron and nickel

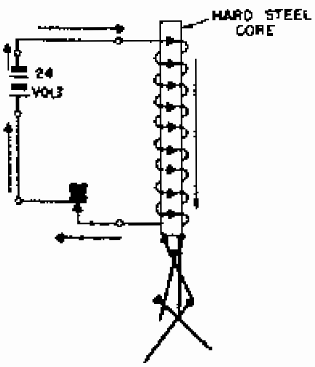


FIGURE 10-8

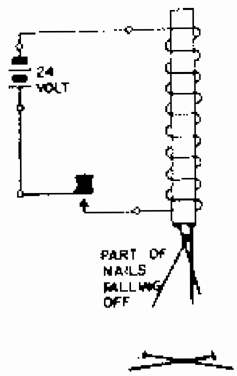


FIGURE 10-9

and is much more efficient than soft iron as a magnetic core.

6.05 When the one end of the electromagnet shown in Figure 10-10 is tested with a permanent bar magnet, it is found to be a north pole. If the other end is tested in a similar way, it will be found to be a south pole. If the direction of the current flow through the coil is reversed the poles will also be reversed, (Figure 10-11).

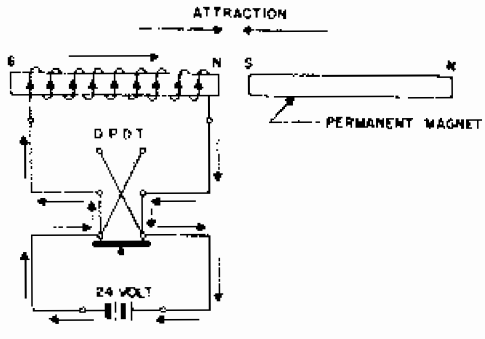


FIGURE 10-10

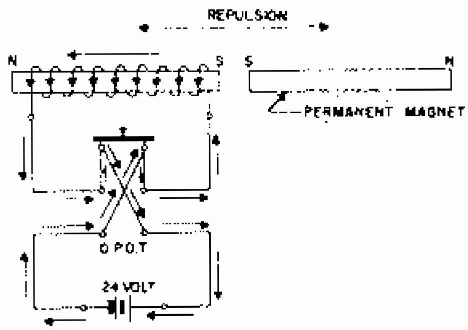


FIGURE 10-11

6.06 Just as a permanent magnet made in the shape of a horseshoe is more efficient than one in the shape of a bar, an electromagnet is more efficient if made in the shape of a horseshoe.

6.07 Figure 10-12 represents an electromagnet in the form of a bar, and Figure 10-13 shows the same magnet after it has been bent into a horseshoe shape. It will be noticed that the latter supports the block, but the former does not.

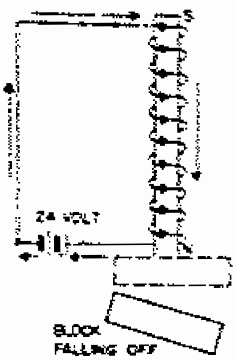


FIGURE 10-12

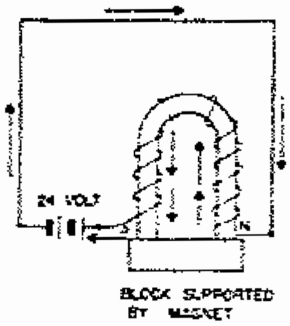


FIGURE 10-13

6.08 In Figure 10-14, an electromagnet and a movable armature have been arranged with a piece of soft iron to concentrate the magnetic field in a magnetic circuit. A small air gap exists between the core of the electromagnet and the armature. A set of electrical contacts have been placed so that the armature will cause them to operate if it moves toward the electromagnet core. Such an assembly is called a relay.

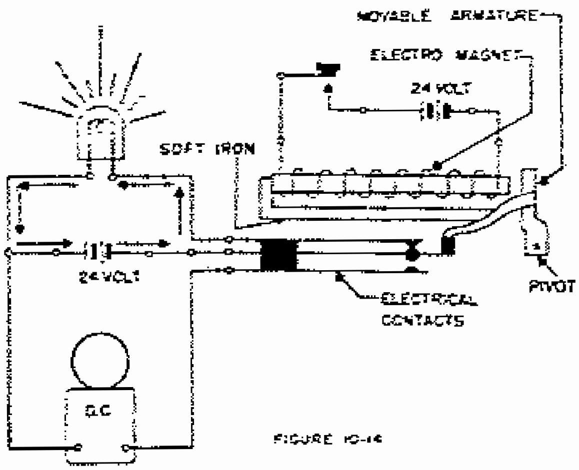


FIGURE 10-14

6.09 When the armature is in its normal position, a circuit is closed through the switchboard lamp.

6.10 When current flows through the coil or winding, the armature is pulled toward the core, opening the lamp circuit and closing the bell circuit. (Figure 15) When the circuit through the winding is broken, the relay releases, opening the bell circuit and closing the lamp circuit again. Thus, an electromagnet may be arranged to open and close circuits.

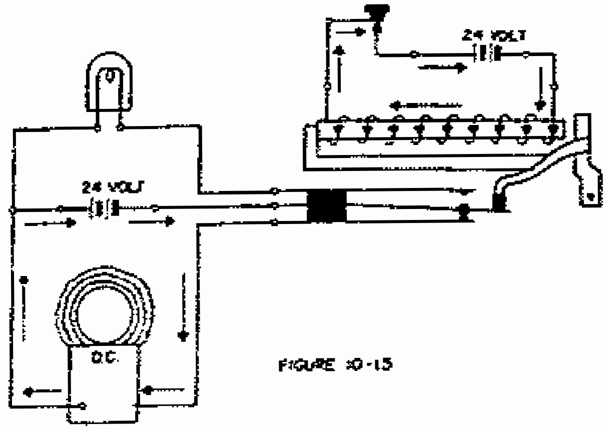


FIGURE 10-15

6.11 Some relays are required to open or close just one circuit when they operate, while others control several circuits. Figure 10-16 is the symbol for a relay with several sets of contacts.

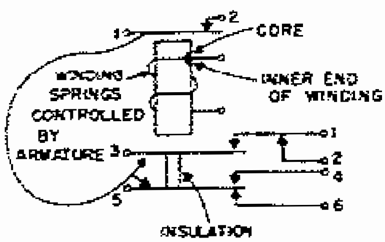


FIGURE 10-16

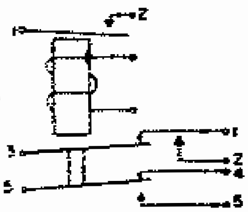


FIGURE 10-17

6.12 Contact springs lower 1 and 2 are in contact. As the armature operates, spring 3 comes into contact with lower 1 and pushes it away from lower 2, as shown in Figure 10-17. This is known as a MAKE BEFORE BREAK arrangement. On the other hand, springs 5 and 6 are in contact when the relay is normal, but as the armature operates, 5 first breaks from 6 and then makes with 4. This is known as a BREAK BEFORE MAKE arrangement. When the armature operates upper 1 breaks from upper 2. This is known as a break arrangement.

6.13 More current is flowing through the winding in Figure 10-19 than in Figure 10-18. The readings of the spring balances show that the pull on the armature is greater in Figure 10-19. The pull on the armature is proportional to the current flowing through the winding.

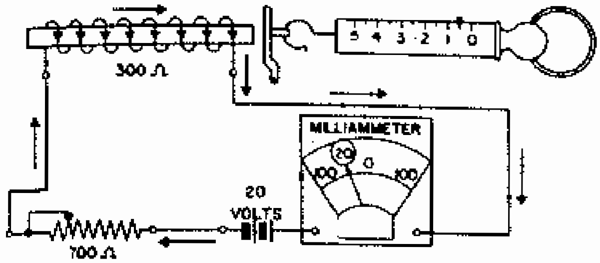


FIGURE 10-18

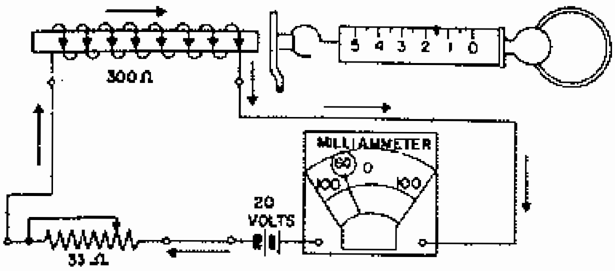


FIGURE 10-19

6.14. A soft iron bridge from a point near the pivoted end of the armature to the opposite end of the magnet, Figure 10-20, has greatly increased the pull on the balance. Thus, as in the case of the permanent magnet the more nearly a complete circuit of iron there is, the stronger the pull.

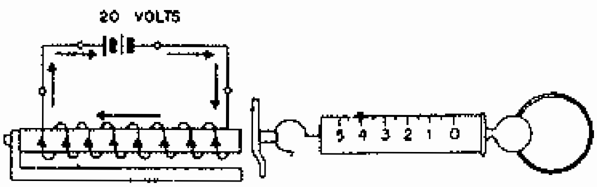


FIGURE 10-20

6.15 The armature in Figure 10-21 is considerable distance away from the end of the core, while in Figure 10-22 the armature is much closer to the core. The readings on the spring balances show that the pull in the latter case is considerably greater. This demonstrates the principle that the closer the armature is to the end of the core, the greater the pull is.

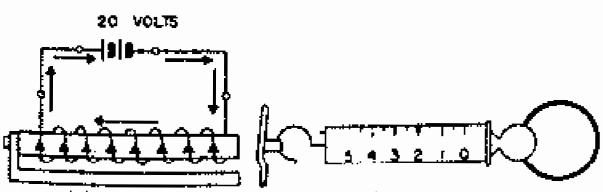


FIG 10-21

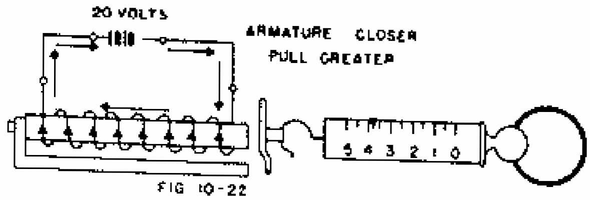


FIG 10-22

6.16 The current flow through the windings shown in Figure 10-23 and Figure 10-24 is the same, but the coil in Figure 10-24 has more turns of wire on it. The readings of the balances show that the latter is pulling the armature harder. For a given current flow the strength of an electromagnet is proportional to the number of turns of wire in the coil.

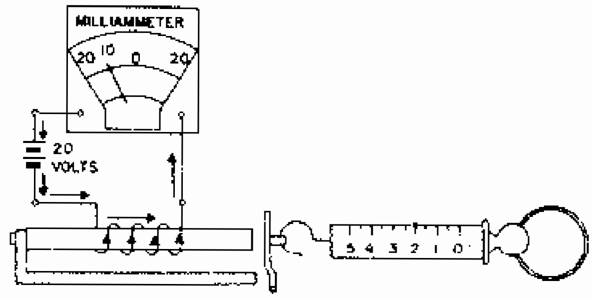


FIG 10-23

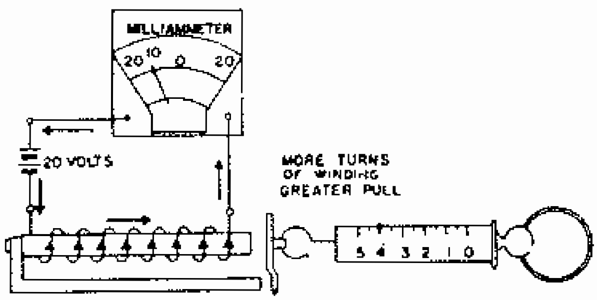


FIG 10-24

6.17 Figure 26 is the same as Figure 25 except that several of the turns of wire on the coil are short-circuited so that no current flows through them. The balance indicates that the pull now is less than it was when the current went through all of the windings. This coil is said to be partially shorted. When the switch in Figure 10-27 is closed, all of the turns of the coil are short-circuited, and there is no pull on the armature.

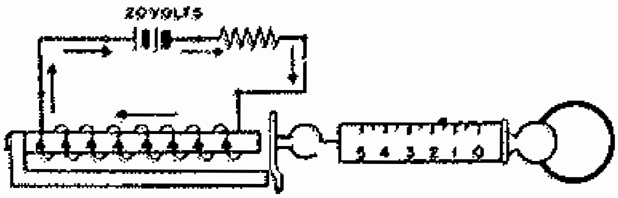


FIG 10-25

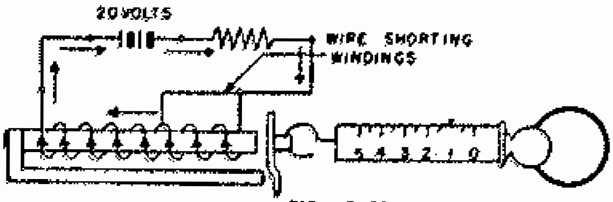


FIG 10-26

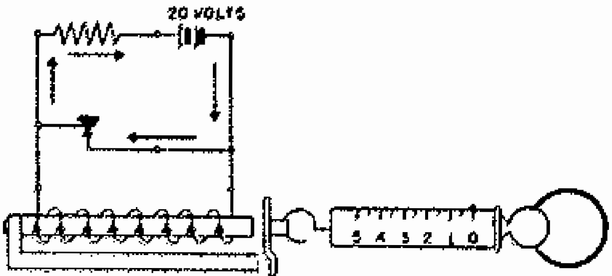


FIG 10-27

6.18 Figure 10-28 represents a relay having a spring to restore the armature to normal. The tension of the spring may be adjusted by means of the adjusting nut. Current is flowing through the winding, but the tension of the spring is greater than the pull on the armature so that the relay does not operate. If almost all of the tension is removed from the spring the relay will operate when the circuit is closed, but will not release when the operating path is again opened, (Figure 10-29).

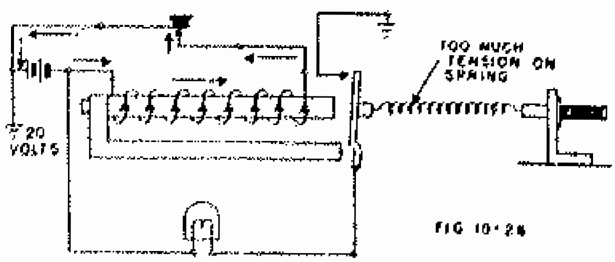


FIG 10-28

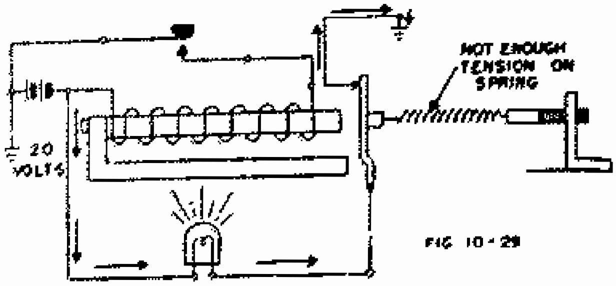


FIG 10-29

6.19 It is apparent that the tension of the restoring spring must not be too great nor too small if the relay is to function properly. When engineers design a circuit they specify the conditions which each relay must meet, and the relays must be adjusted accordingly.

6.20 Sufficient current is flowing in the circuit shown in Figure 10-30 to light the lamp, but not to operate the relay. However, when the key is closed the increase in the current flow is sufficient to operate the relay (Figure 10-31).

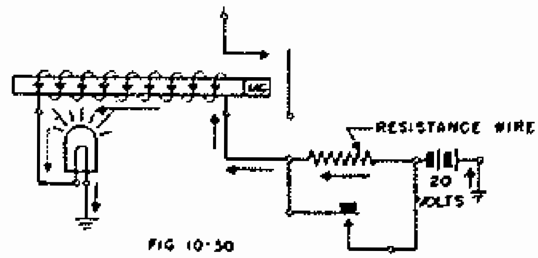


FIG 10-30

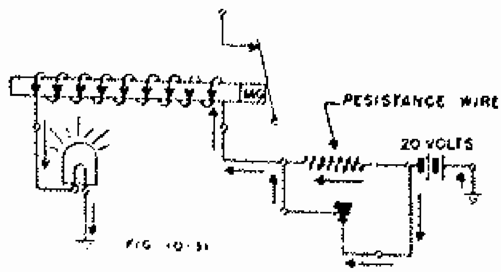


FIG 10-31

6.21 Relays which are adjusted to operate on a very definite current flow are called marginal relays. The letters MC on the core of a relay symbol indicates that it has a marginal adjustment.

6.22 Relays "A" and "B" shown in Figure 10-32 are marginal. The current flowing in the circuit as shown is sufficient to operate relay "B" but not relay "A". When the path through relay "C" is closed, the current through relay "A" is increased enough to cause it to operate. (Figure 10-33) This greater flow is split between relay "B" and relay "C". Since relay "C" has much less resistance than relay "B", leaving less than enough current flowing through relay "B" to hold it operated. That is, relay "C" shunts relay "B" and at the same time increases the flow through relay "A" and causes it to operate.

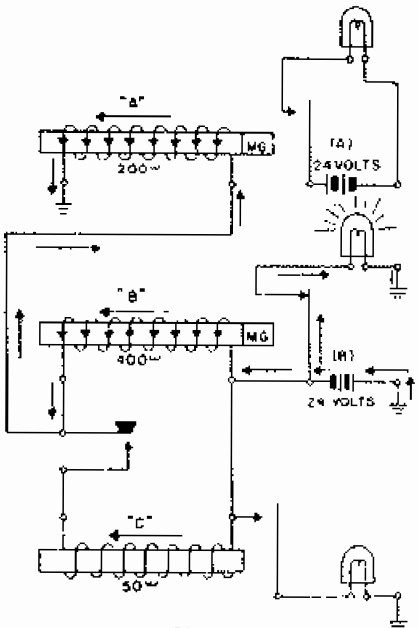


FIG 10-32

6.23 Current flows through windings No.1 and No.2 of relay "A", Figure 10-34 in the same direction. The magnetic strength is, therefore, the sum of the strengths produced by each winding. With relay "B" operated, however, the direction of the current flow through winding No.2 is reversed, as is indicated by the arrows. Thus, windings Nos.1 and 2 work against each other and the pull on the armature is that produced by the difference of the strengths produced by each coil, and is not sufficient to operate the relay, (Figure 10-35). These are called

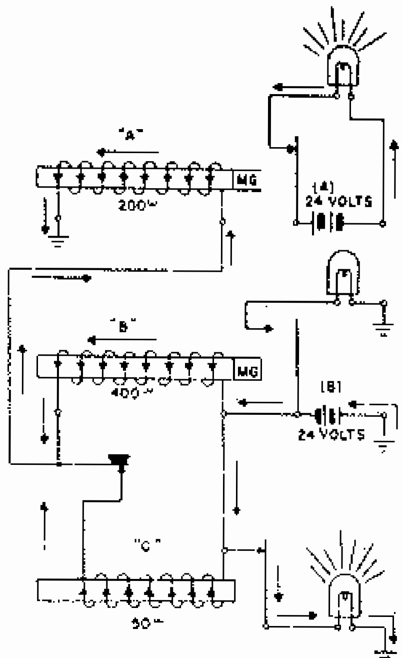


FIG 10-33

differential windings, or the relay is said to be differentially wound. Winding No.1 may be called the Primary winding and No.2 the Secondary winding. If a third winding were included, it would be known as the tertiary winding. Figure 10-36 shows how the windings of such a relay are marked on the symbol.

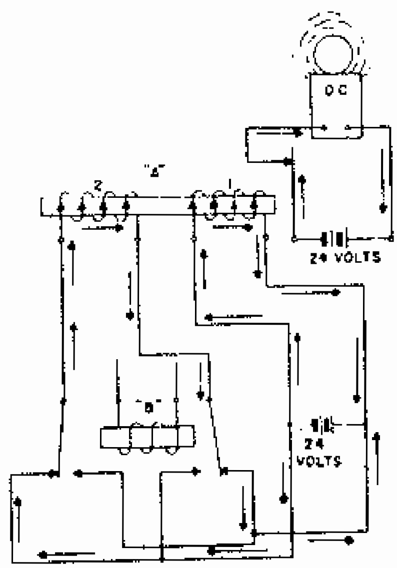


FIGURE 10-34

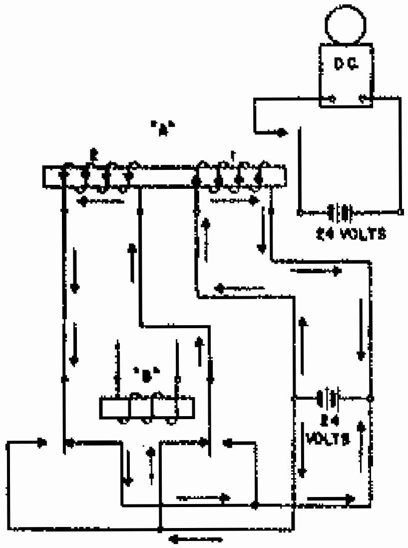


FIGURE 10-35

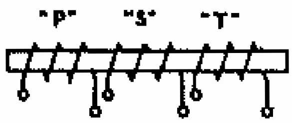


FIG 10-36

6.24 In Figure 10-37 an iron rod has been started into the end of the hollow coil. When the circuit through the coil is closed, the iron rod is drawn up into the coil, (Figure 10-38). However, when the circuit is opened, the rod drops out, (Figure 10-39). A coil that is designed to pull a rod, or armature into itself is called a <u>solenoid</u>. It combines a strong pull with a long armature travel and is used for various purposes, such as to operate a set of contacts, compress a spring, etc.

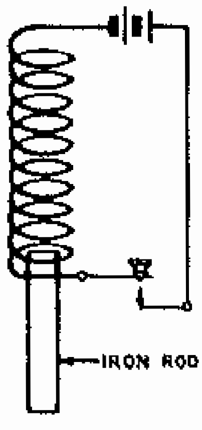


FIG 10-37

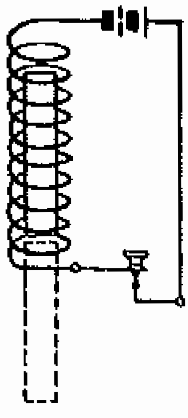


FIG 10-38

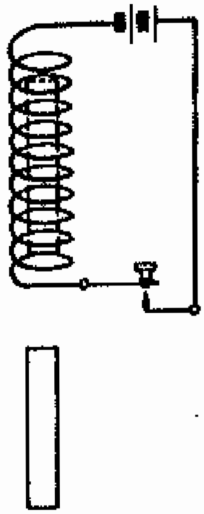


FIG 10-39

6.25 Figure 10-40 shows a solenoid magnet arranged to close a set of contacts when it operates. However, the armature is also connected to a piston fitted into a cylinder filled with oil. When the piston is pulled upward it draws oil in through the bottom of the cylinder. If this passage is small it takes considerable time for the armature and piston to travel far enough to operate the contacts.

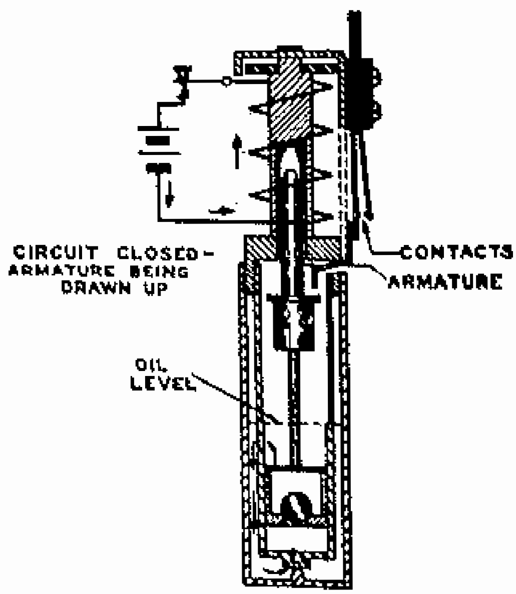


FIG 10-40

6.26 By screwing the outer cover up or down, the size of the opening at the bottom of the cylinder may be changed. Thus, the time required for the relay to operate may be varied from a few seconds to several minutes. When the circuit is broken, the armature and piston start downward. The ball valve now opens permitting the oil to flow freely through the piston so that the relay releases quickly (Figure 10-41). This is known as a dashpot relay.

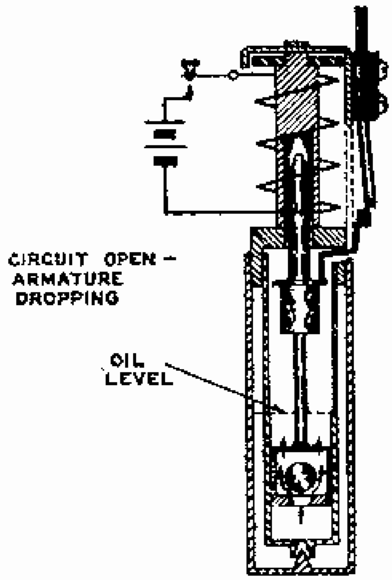


FIG 10-41

7. POLARIZED RELAY

7.01 Figure 10-42 represents a type of relay known as the polarized relay. It consists of an iron reed or armature suspended inside of a hollow coil. One end of the armature passes midway between the poles of a permanent horseshoe magnet. When electrons flows through the winding of the electromagnet in the direction shown, the end of the armature between the pole pieces becomes a south pole and the other end a north pole.

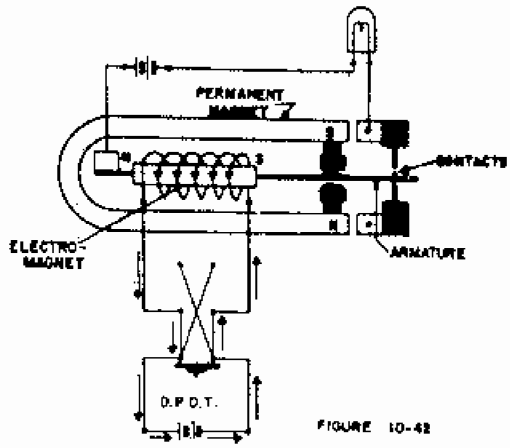


FIGURE 10-42

7.02 The south pole of the armature is attracted by the north pole of the permanent magnet. This merely causes the armature to press harder against the stop. When current flows through the winding in the opposite direction, the poles of the armature are reversed, and its north pole is attracted by the south pole of the permanent magnet. This caused the armature to operate and close the contacts, (Figure 10-43).

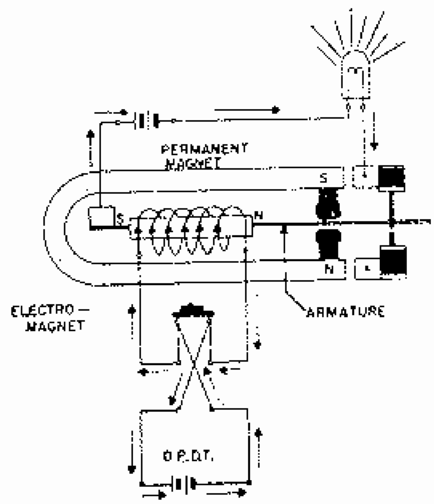


FIGURE 10-43

8. COIN RELAY

8.01 Figure 10-44 represents a bar magnet whose south pole end has been split and spread so that each half of the south pole is on one side of the north pole. In Figure 10-45 the south pole of a permanent bar magnet is in contact with the center of an iron frame. If each of the three ends are tested, their polarity will be found to be the same as of the corresponding parts of the split magnet.

FIG. 10-44

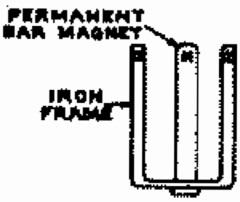


FIG. 10-45

8.02 An iron armature is pivoted above the north pole of the magnet in Figure 10-46. The ends of the armatures are both north poles, due to their nearness to the south poles of the magnet. If the armature is rotated slightly in either direction it will continue until it strikes the frame.

8.03 Two springs have been added in Figure 10-47 to keep the armature in a neutral position.

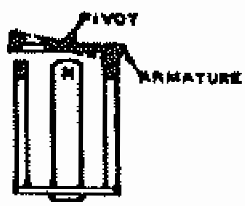


FIG. 10-46

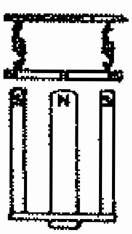


FIG. 10-47

8.04 The two coils shown connected in series in Figure 10-48 create Magnetic Poles as indicated.

8.05 In Figure 10-49 the coils have been placed upon the two south pole arms of the permanent magnet assembly.

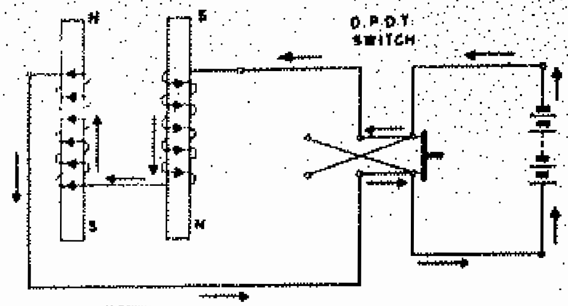


FIG. 10-48

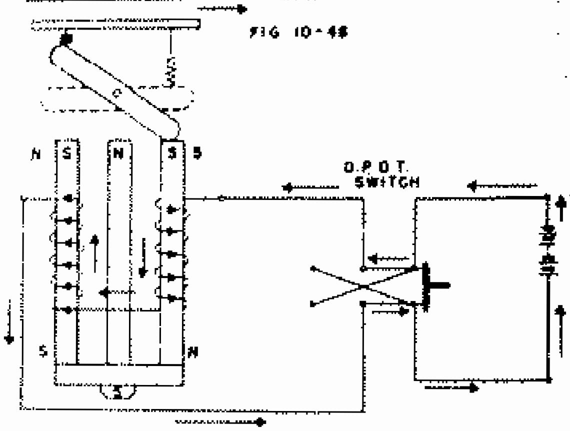


FIG. 10-49

On the right side of the south poles the permanent magnet and the coil combine to make a stronger south pole, while on the left side the south pole of the permanent magnet is combined with the north pole of the coil. The armature is, therefore, rotated to the right until it strikes the pole piece on that side.

8.06 When the current flow is reversed as in Figure 10-50 the armature rotates to the left. When current flows through the winding in one direction, the armature will rotate to the right, and when the current flow is in the opposite direction, the armature will rotate to the left.

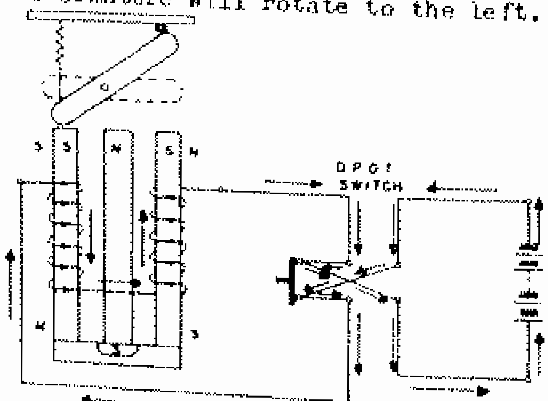


FIG. 10-50

8.07 The coin collector mechanism in a pay telephone uses such a device. The armature is connected mechanically to a coin control mechanism. When current is sent through the circuit in one direction, the coin is allowed to fall into the cash box; but when the current is sent in the opposite direction, the coin is returned.

8.08 The permanent magnet in the mechanism in Figure 10-51 has lost its strength so that when current flows through the winding, the armature is affected only by the magnetism created by the coils. The end of the armature over the north pole of electromagnet becomes a south pole and the other end a north pole. If the armature were exactly balanced it would not rotate at all. However, in this case the right end of the armature is nearer to the south pole than the left end is to the north pole. As a result, the armature operates to the right.

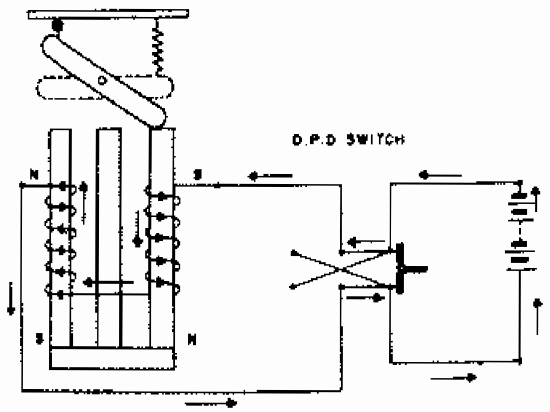


FIG 10-51

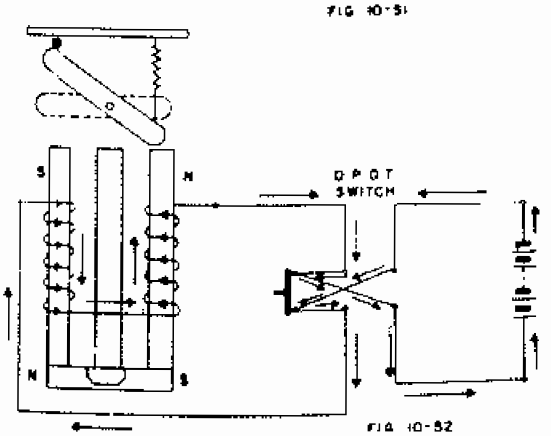


FIG 10-52

8.09 When the current is reversed, the armature again operates to the right, (Figure 10-52). Thus; it is seen that the permanent magnet is essential for the proper operation of this device.

9. LOSSES IN ELECTROMAGNETS

9.01 When the magnetism of an electromagnet is rapidly reversed, that is, when the direction of the lines of force is changed several times in rapid succession by reversing the direction of the magnetizing current, the iron core becomes heated and a certain amount of energy will be expended. This heating effect is due to two causes:

a. Hysteresis, which is molecular friction caused by the change in position of the molecules of the iron.

b. Eddy Currents, which are currents that are induced in metal whenever the metal is moved in a magnetic field, or when the metal is cut rapidly by a moving magnetic field.

These factors will be discussed further in the chapter on transformers, repeating coils, and inductance coils.

In order to reduce to a minimum the heating effects, and hence losses, due to eddy currents, the cores of electromagnets are sometimes composed of bundles of iron wires or sheets, insulated from each other to hinder the eddy currents. These are known as laminated cores.

10. QUESTIONS

1. Is an electrical current always accompanied by magnetic lines of force?

2. What form do the magnetic lines of force take around a conductor carrying an electrical current?

3. State the left hand rule for determining the direction of the magnetic field of force around a conductor carrying current.

4. What determines the direction of the magnetic field of force around a conductor carrying current?

5. What is the difference between a solenoid and an electromagnet?

6. Has a solenoid a definite north and south pole, when carrying an electrical current?

7. State the left hand rule for determining the polarity of a solenoid.

8. What is magnetomotive force?

9. What substance generally is used for the cores of electromagnets?

10. What two methods are used to increase the strength of an electromagnet?

11. How could the batteries in Figure 10-53 be connected to the two windings so that current would flow in both, but not operate the relay?

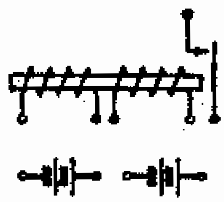


FIG. 10-53

12. Relay "B" in figure 10-54 operates when the key is closed, but relay "A" does not, even though there is no spring tension against its armature. Does this indicate that the winding of relay "A" is open or shorted?

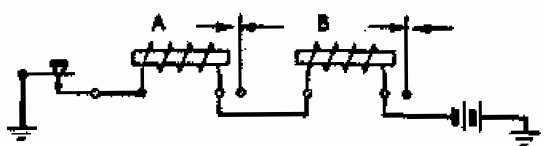


FIG. 10-54

13. Relays "A" and "B" in Figure 10-55 are just alike, but relay "B" fails to operate when the key is closed. How could the test lamp be used to determine if the winding is open? If it is partially shorted?

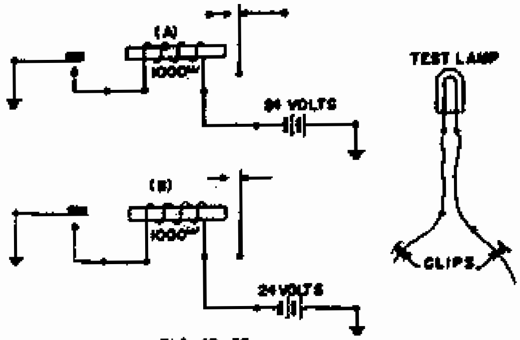


FIG. 10-55

14. Why are the cores of electromagnets laminated?

15. What is the difference between a polarized relay and an ordinary relay?

16. Is the coin relay a polarized relay?

17. Is the permanent magnet necessary for the proper operation of the coin relay?

CHAPTER XI

D. C. METERS

1. MEASUREMENT OF ELECTRICITY

1.01 An electrical current may be defined as the movement of free electrons along a conductor. Since it is known that electrons are so small as to be invisible, the only means of detecting or measuring electricity is by the effects which it produces.

1.02 The effects important to electrical measurements are;

a. The heating effect - Whenever a current flows through a path offering considerable resistance, heat is produced.

b. The magnetic effect - A current produces a magnetic field in its vicinity which can be shown by the attraction or repulsion of another magnet.

c. The chemical effect - Current in passing through certain chemical solutions will cause chemical actions to take place.

2. STANDARD MEASUREMENT

2.01 The chemical effect is used as standard with which to define the unit of current. Although used as a standard, the chemical method is not suitable for ordinary measurements as it takes considerable time and requires very precise measurements of weight and time.

2.02 Since the electromagnetic method gives almost instantaneous measurements with a minimum amount of skill necessary on the part of the measurer, most of the common measuring instruments employ this method in their operation.

3. THE D'ARSONVAL GALVANOMETER

3.01 The D'Arsonval galvanometer, in its simplest form, consists of a coil of wire suspended between the two poles of a permanent magnet. As a current is passed through the coil, a magnetic field is set up around the coil having a definite north and south pole in accordance with the left hand rule. The coil will then turn, attempting to align itself so that its north pole is as close to the south pole of the permanent magnet as possible.

3.02 In the direct current meter shown in Figure 11-1, the D'Arsonval principle of movement is employed.

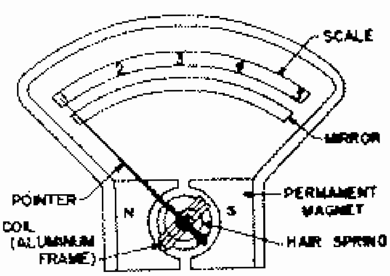


FIG. 11-1

Certain structural arrangements are embodied which provide a maximum of ruggedness with a minimum loss of sensitivity. In order to reduce friction the coil is pivoted in jewels. The coiled hair spring tends to keep the coil from turning, thereby providing a force which resists that set up by the reaction between the magnetic fields of the coil and the permanent magnet. By proper design of the hair spring, magnetic circuit and of the the pointer can be made proportional to the amount of current flowing in the coil. The coil and pointer are mechanically balanced so that the instrument may be used in any position. A mirror is placed next to the scale and beneath the pointer so that errors in reading the scale due to parallax can be avoided.

3.03 The inertia of the coil and the resilience of the hair spring tend to cause the pointer to oscillate about the reading point on the scale, for a time after the current is applied. The reduction of this tendency is called damping. In most meters a closed conducting loop, usually the frame on which the coil is wound, acts as a damper. As the coil moves in the strong field of the permanent magnet, a current is induced in the aluminum frame which in turn produces a magnetic field that opposes the movement of the entire coil structure, acting as a brake to keep the pointer from oscillating. When the pointer is at rest, there is no current induced in the aluminum frame.

3.04 In studying the action and construction of direct-current meters, the question might arise as to the difference between ammeters and voltmeters, since they both employ the D'Arsonval galvanometer principle of movement. In a galvanometer there is no provision for measuring the amount of current flowing through the coil. In this respect the galvanometer acts more as a detector of current than as a measurer. The ammeter is a galvanometer which has been calibrated in amperes so that the amount of current can be read directly from a scale. The voltmeter is a galvanometer calibrated in volts, and is so constructed that the small amount of current necessary to deflect the pointer is in proportion to the voltage being measured.

3.05 It must be remembered that when this type of ammeter or voltmeter is used, it consumes power and becomes, in reality, a part of the circuit being measured. The amount of power consumed is negligible in most cases and does not materially affect the accuracy of the measurement.

4. AMMETER

4.01 All of the current flows through the coil of the galvanometer. The magnetic field produced by this coil does not have to be very strong to move the pointer, since the only opposition encountered is the tension of the coil spring and the friction of the jeweled pivots. Therefore, a very small amount of current will move the pointer the full length of the scale. In direct-current instruments this may be from .0001 to .035 amperes. In order to reach a large current flow, it is necessary to divert most of the current over a different path than through the coil, thus allowing only a small percentage of the total current being measured to pass through the coil of the meter. This diversion is accomplished by adding an additional path of low resistance in parallel with the coil of the meter. This additional path is called a shunt. The shunt circuit illustrated in Figure 11-2 shows that a parallel circuit is made with the resistance of the coil as one branch, and the resistance of the shunt as the other branch. The amount of current in the coil will depend on the relationship between the resistance of the coil and the resistance of the shunt.

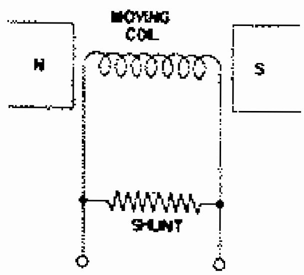


FIG 11-2

4.02 By changing the resistance of the shunt, the range of the instrument can be extended so that the ammeter can measure many times the amount of the current necessary for full scale deflection of the pointer. This is done by providing a shunt having lower resistance than the coil, thereby causing most of the current to flow through the shunt, but allowing enough through the coil to provide a readable deflection of the pointer.

4.03 In determining the value of shunt necessary, Ohm's law as applied to parallel circuits is used. For example, in the circuit shown in Figure 11-3, R_A represents the coil of an ammeter which has a resistance of .02 ohms. When .01 amperes flows through the coil, the ammeter gives full scale deflection. It is desired to measure .5 amperes of current with the meter and the problem is to find the value of shunt, R_S, necessary to increase the range of the instrument from .01 to .5 amperes. Since the coil itself can carry .01 amperes, then the amount of current which must flow through the

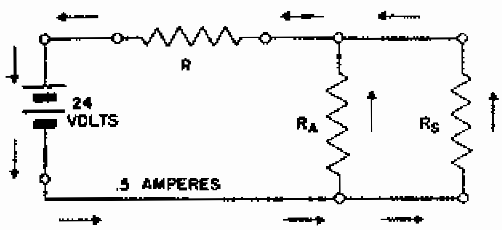


FIG. 11-3

shunt is .5 - .01 or .49 amperes. The voltage drop across the ammeter coil, R_A, is calculated by applying Ohm's law to the circuit. This equals .01 x .02 or .0002 volts. Since the shunt, R_S, is in parallel with R_A the voltage drop must be the same across the two resistances. Therefore, dividing the voltage drop by the current through the shunt will give the resistance necessary in the shunt; .0002 ÷ .49 = .0004 ohms.

4.04 If the maximum reading of a meter is changed the scale of the meter must also be changed, or a multiplying value calculated for converting scale readings. For example, suppose an ammeter which reads a maximum of 3 amperes is changed by the addition of a shunt, so that the maximum amount of current which can be measured is 30 amperes. The shunt added to the meter has a multiplying value of 10, and the reading on the three ampere scale would be multiplied by 10 in order to obtain the correct value of current.

5. VOLTMETERS

5.01 The voltmeter is a galvanometer to which has been added resistance in series with the coil, instead of in parallel as in the ammeter. In order to draw as little current as possible from the circuit, the meter coil should require a very small amount of current, and the resistance connected in series should be large. This series resistance in a voltmeter is known as a multiplier.

5.02 The use of a multiplier may be illustrated by the following example: In the circuit shown in Figure 4, a voltmeter is connected across the resistance R_2 to measure the potential drop of that resistance.

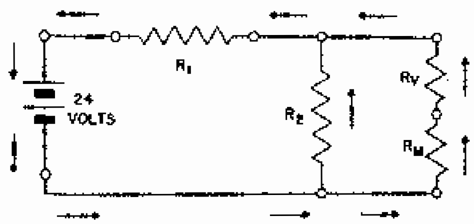


FIG 11-4

Assume the resistance of R_2 is 4 ohms, the current flowing through R_2 is .5 amperes, the resistance of the voltmeter coil, represented by R_V, is .02 ohms, and the amount of current necessary for full scale deflection is .01 amperes. The problem is to determine the value of the multiplier, R_M that will give the correct voltage drop across R_2. To determine the voltage drop of R_2, multiply the current by the resistance; .5 x 4 = 2 volts. Since the voltmeter is connected in parallel with the voltage being measured, the total voltage drop across R_V and R_M will be 2 volts. The maximum current that can flow through the voltmeter coil without damaging the instrument is .01 amperes. The combined resistance must be such that the current will be limited to this value. Dividing the voltage drop by the current will give the total resistance needed; 2 ÷ .01 = 200 ohms. The resistance of RV is .02 ohms; therefore the resistance of the multiplier will be 200 - .02 or 199.98 ohms.

6. OHMMETER

6.01 The average ohmmeter that is used in the field is merely an adaptation of the D'Arsonval galvanometer. In this device the galvanometer is connected to a known voltage source such as a dry cell. The unknown resistance is connected in series with the dry cell and galvanometer. The galvanometer deflection will be an amount determined by the unknown resistance. By using Ohm's law, the galvanometer resistance and the dry cell voltage, it is possible to calibrate the meter deflection in ohms. Various resistance ranges may be obtained by inserting known values of resistance (calibrating resistors) in series with the galvanometer. Sometimes it becomes necessary to increase the supply voltage depending upon the sensitivity of the galvanometer.

7. QUESTIONS

1. What are the three ways that electricity in motion manifests itself?

2. Which of the above effects is used to measure the amount of current?

3. Which method of measuring an electrical current is used as the standard?

4. What are the disadvantages of using the chemical effect for measurements?

5. What type of galvanometer is used in most of the ammeters and voltmeters employing the electromagnetic effect for measurement of direct currents?

6. Define damping. How is it accomplished?

7. State the difference between galvanometers, ammeters, and voltmeters.

8. Should an ammeter have high or low resistance? Why?

9. Should a voltmeter have high or low resistance? Why?

10. It is desired to convert a galvanometer of 0.2 amperes full scale reading to a 4 ampere meter. The galvanometer reads full scale when 0.1 volt is applied to the terminals. What value of shunt is required?

11. What would be the multiplying value of the shunt in question 10?

12. What is the purpose of an ammeter shunt?

13. What is a multiplier? In what instrument is the multiplier used?

14. What law is used to calculate meter deflection of an ohmmeter?

15. What determines the supply voltage for an ohmmeter?

CHAPTER XII

NATURE OF ALTERNATING CURRENT

1. GENERATION

1.01 In the preceding discussions the source of e.m.f. was assumed to be a battery. This was done for the sake of convenience and simplicity. However, as a source of commercial electric energy on a large scale basis, the battery is relatively expensive and unwieldy, and it is necessary to use some other means of obtaining electric energy in bulk. Probably the most common means of accomplishing this is through the use of the generator, which depends for its operation upon the phenomenon of electromagnetic induction.

1.02 In an earlier discussion it was shown that when e.m.f. is impressed on a conductor and electrons are made to flow through the conductor, the motion of this current of electricity produces a magnetic field of force about the conductor. The reverse of this is also true. A magnetic field can be made to create an e.m.f. and thereby cause a current to flow in a closed loop. This creation of an e.m.f. is accomplished by moving a conductor so that it cuts across lines of force, or moving the lines of force so that they cut across the conductor.

1.03 The wire "ab" in Figure 12-1 is connected to a very sensitive galvanometer. When the wire is moved past the north and the south magnetic poles as shown, the needle is deflected, indicating that a current is flowing. If the wire is moved past the poles in the other direction, Figure 12-2, the needle is deflected to the other side, indicating that the current flow has been reversed. However, if the wire is moved directly from either pole to the other, as shown in Figure 12-3, the meter needle is not deflected.

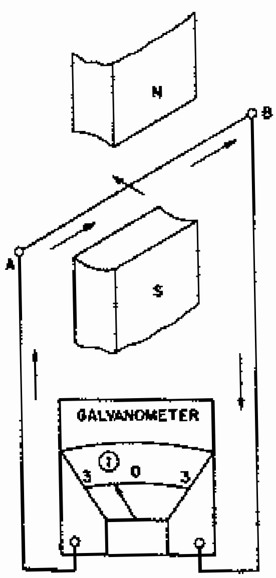


FIG. 12-1

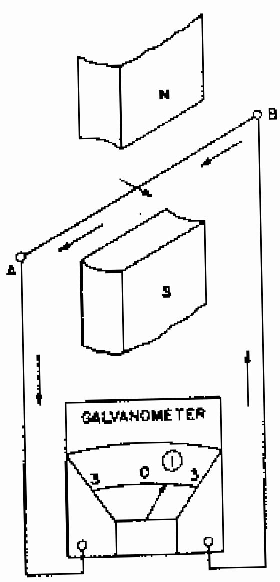


FIG. 12-2

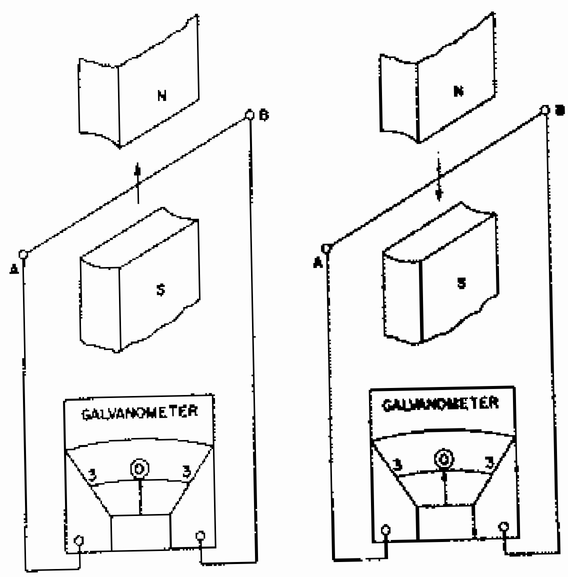


FIG. 12-3

1.04 Each end of the loop of wire shown in Figure 12-4 is connected to a metal ring which slides past a carbon brush when the loop is rotated.

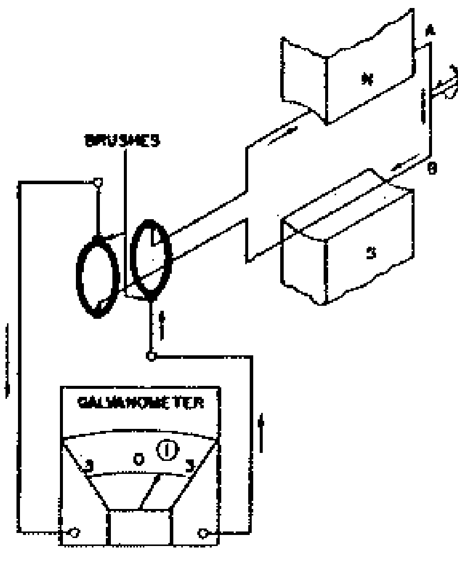


FIG. 12-4

If the loop is being rotated through the position shown, current flows as indicated. As the loop turns farther, the current is diminished until it is zero at the time when the loop is in the position shown in Figure 12-5, where side A is traveling from the N pole to the S pole and side B is traveling from the S pole to the N pole.

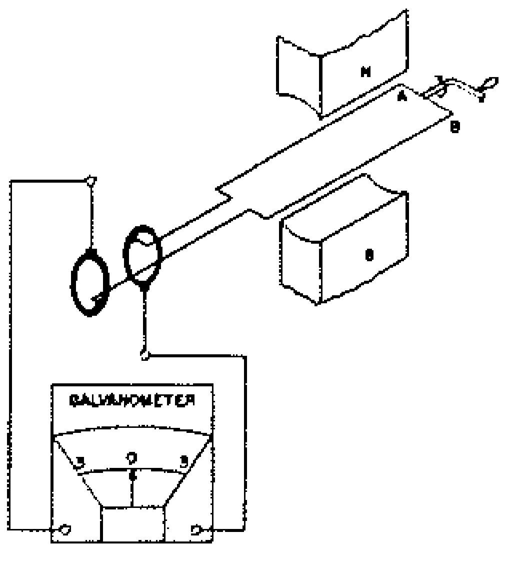


FIG. 12-5

When the loop advances farther, current starts to flow in the opposite direction and increases until the loop is in the position shown in Figure 12-6 where side A is moving directly past the S pole and side B is moving in the opposite direction past the N pole.

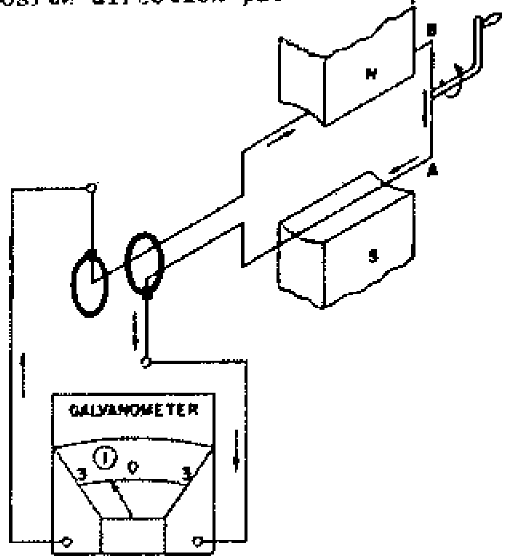


FIG. 12-6

The current then decreases, becoming zero as the loop reaches the position shown in Figure 12-7. Thus, it is seen that by rotating the loop between the two opposite magnetic poles a current is caused to flow first in one direction and then in the other. Such a device is a simple kind of ALTERNATING CURRENT GENERATOR. The loop is known as the armature and the space between the poles as the magnetic field.

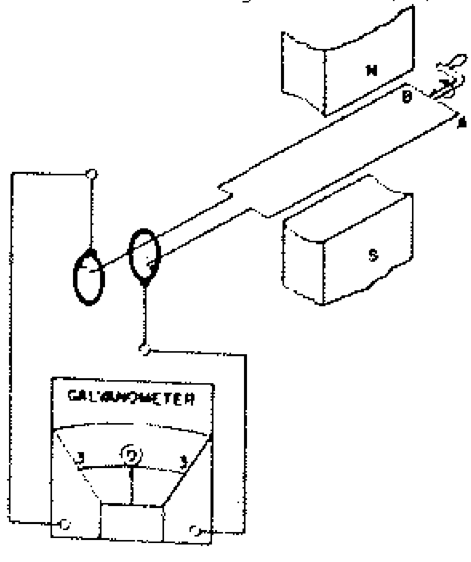


FIG. 12-7

1.05 Figure 12-8b indicates graphically the current flow as the loop is being turned in 12-8a. At point A, the conductor is moving parallel to the lines of force and since no lines are being cut, the current induced is zero; represented graphically by point A'. As the conductor advances from A to B, it is cutting a greater amount of flux at each instant, giving a slow increase in current as shown by the curve 12-8B, (A' to B') At C the wire is moving perpendicular to the flux and therefore cutting the maximum number of lines of force which induces the maximum current as shown by the point C'. Note that the conductor has moved through an angle of 90° from A to C. As the conductor moves on past C, it is cutting a decreasing amount of flux at each instant, thereby decreasing the induced current as shown by the curve C' to D'. At the instant E, the conductor has made one-half revolution and is again moving parallel to the lines of flux, inducing no current as shown by E' in Figure 12-8B. When the position E is passed, the direction of current changes as the conductor now moves upward cutting flux in the opposite direction. Progressing as before, the current gradually increases in a negative direction, until at point G, the conductor is again moving perpendicular to the flux, giving maximum negative current, as shown by G'. From G to A the induced current gradually decreases, until, again at position A it is zero, represented by A" and the conductor and wave are ready to start another cycle. Points A' and A" on the wave represent the same position of the conductor, A.

1.06 The curve 8B as plotted in the preceding paragraph, is known as a sine wave. The sine wave is a smooth curve that represents the polarity and magnitude of the instantaneous values of the current, and is the normal wave form for an alternating current. The horizontal base line is divided into degrees or intervals of time, and the vertical distance of the wave above or below the base line represents the instantaneous value of current at a particular point in the rotation of the loop.

1.07 The preceding discussions of alternating current generation have been based on current flow. It can be readily understood that an e.m.f. or voltage analogy would apply in the same sense. In other words either current or voltage magnitudes and polarities may be plotted as a sine curve.

1.08 Whenever anything passes through a series of changes and returns to the starting point, there to again start the same series of changes, it is called a cycle. Figure 12-8B represents a cycle of current. The current increases from zero to a maximum positive value, decreases to zero, increases to a maximum negative value, and again decreases to zero, there to again start the same series of change.

1.09 An alternation is one-half of a cycle. See Figure 12-8b.

1.10 The frequency of electricity is normally expressed in cycles per

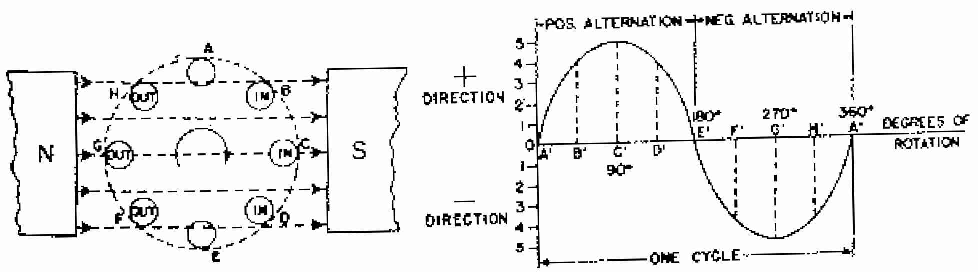


FIG 12-8

second; however, in some instances the words, per second, are omitted. Frequency refers to the number of complete cycles occurring in one second. If the conductor in Figure 12-8a was turning at 3600 revolutions per minute, or 60 revolutions per second, there would be 60 cycles of e.m.f. generated per second. The frequency of this e.m.f. would be 60 cycles per second. Then the conductor would complete one revolution in 1/60 of a second; one-half revolution in 1/120 of a second and one-quarter of a revolution in 1/240 of a second. Therefore, the horizontal base line in Figure 12-8b may be termed a time or degree reference line.

1.11 A coil composed of three turns of wire is being rotated in the magnetic field in Figure 12-9. The e.m.f. created in this case is three times as great as if there were only one turn, see figure 12-4, and, consequently, three times as much current flows through the meter; that is, THE E.M.F. CREATED IS PROPORTIONAL TO THE NUMBER OF TURNS WHICH PASS THE POLES AT THE SAME TIME.

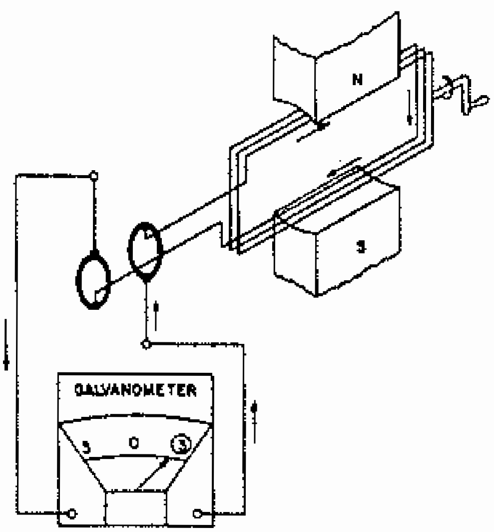


FIG. 12-9

1.12 In Figure 12-10 the magnetic poles are twice as strong as in Figure 12-4 and the voltage produced is twice as great; that is, the E.M.F. IS ALSO PROPORTIONAL TO THE STRENGTH OF THE MAGNETIC POLES.

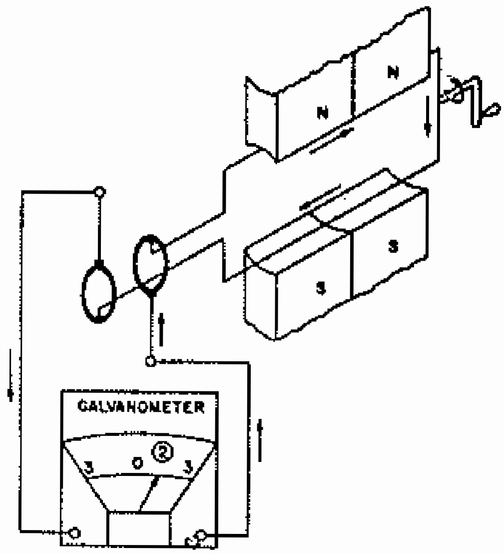


FIG. 12-10

1.13 It was shown in Chapter IX that by placing iron in the space between the poles of a magnet the magnetic effect can be increased. Therefore, IF AN IRON CORE IS PLACED INSIDE OF THE ARMATURE LOOP, THE VOLTAGE PRODUCED WILL BE INCREASED. Likewise, it may be shown that VOLTAGE OF A GENERATOR IS PROPORTIONAL TO THE SPEED AT WHICH THE ARMATURE IS ROTATED.

2. QUESTIONS

1. Describe an alternating current.
2. What three factors determine the value of the induced current?
3. Draw a sine wave representing one cycle of alternating voltage.
4. Is the value of the induced current in a conductor which is rotating in a magnetic field, the same at every instant? Explain why.

5. Does the polarity of a.c. change?

6. How many revolutions of a single loop revolving between the poles of one horse-shoe magnet, is necessary to produce one cycle of alternating voltage?

7. If additional turns are added to a single loop armature, will the frequency change?

8. What happens to the current of an armature if the turns are increased from one to ten?

9. What does a sine curve of voltage represent? A sine curve of current?

CHAPTER XIII

D. C. GENERATORS

1. GENERATION

1.01 A direct current generator always causes a current to flow in the same direction.

1.02 The ends of the armature loop in Figure 13-1 are each connected to one segment of a split ring called a commutator. With the loop in motion and in the position shown the current flow through the meter is as indicated.

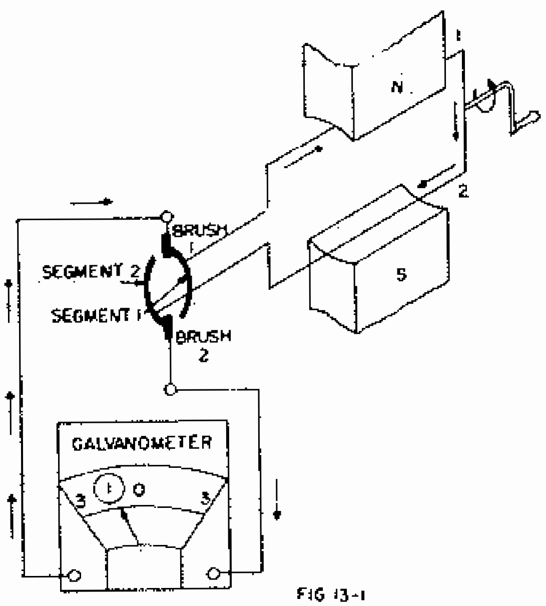


FIG 13-1

It will be noticed that brush 1 is in contact with commutator segment 1, and brush 2 with segment 2. While the loop is passing through the opposite position, Figure 13-2, the flow through the loop is in the opposite direction, but brush 1 is now in contact with segment 2 and brush 2 with segment 1.

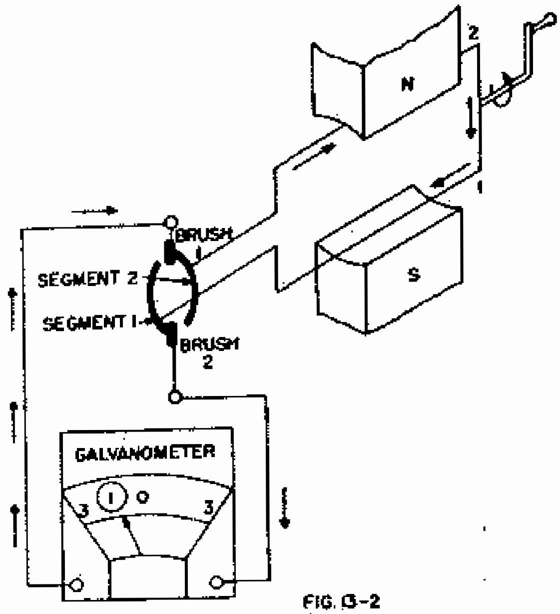


FIG. 13-2

Consequently the flow through the meter is in the same direction as when the coil was in Figure 13-1. Figure 13-3 represents the voltage across the brushes as the armature is turned.

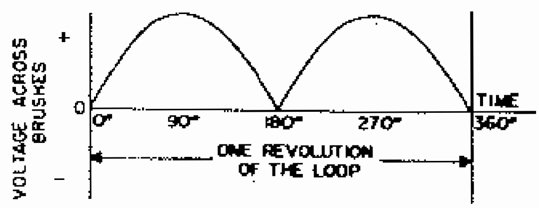


FIG. 13-3

1.03 The commutator in Figure 13-4 has four segments and two loops arranged as shown. With this arrangement there is always an E.M.F. being produced by the generator. The solid lines in Figure 13-5 represent the voltage at the brushes, while the dotted portions represent the voltages produced by each loop. If more loops and segments are added in a similar manner, the voltage of the brushes will be more nearly constant.

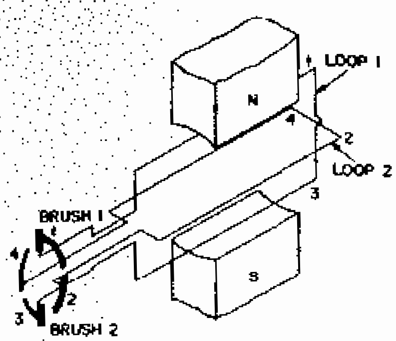


FIG. 13-4

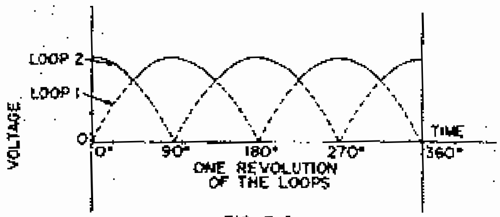


FIG 13-5

1.04 If the magnetic poles are those of permanent magnets, the generator is often called a magneto. However, the magnetic field may be created by electromagnets. Figure 13-6 shows a generator having electromagnets created by the current flow from a battery. This generator is said to be separately excited, and is represented by the symbol shown in Figure 13-7.

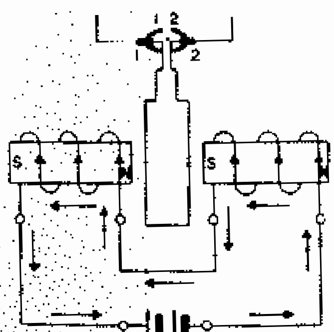


FIG. 13-6

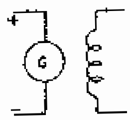


FIG 13-7

1.05 Part of the current from the armature of the generator shown in Figure 13-8 flows through the electromagnets, known as field magnets, to energize them. By adjusting the field rheostat, the magnetic strength and consequently the voltage of the generator may be varied. This type of device is known as a Shunt wound generator. It may or may not be equipped with a field rheostat. Figure 13-9 shows the symbol for such a generator equipped with the rheostat. The voltage of a shunt machine is less when it is connected to a low resistance circuit than when connected to one of high resistance.

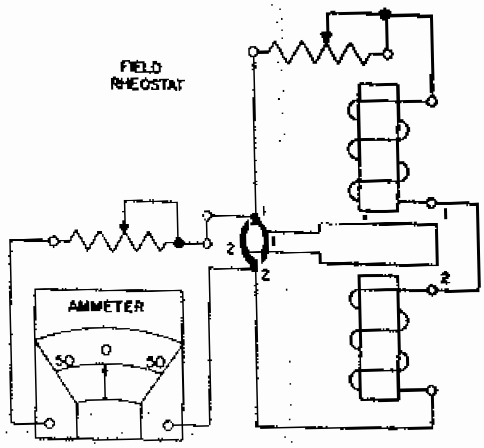


FIG 13-8

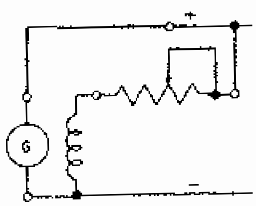


FIG. 13-9

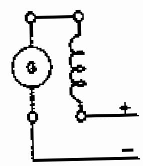


FIG. 13-10

1.06 All of the current coming from the armature of the machine represented in Figure 13-10 flows through the field windings. This is said to be a series wound generator. The voltage of a series generator is greater when connected to a low resistance circuit then when connected to a high resistance. one.

1.07 A combination of a shunt winding and a series winding are used in Figure 13-11. This is known as a compound wound generator. Varying the resistance of the load connected to a compound generator does not greatly affect the voltage across the terminals of the generator.

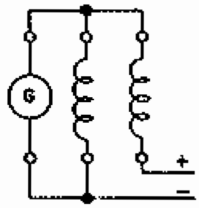


FIG. 13-11

2. GENERATORS IN SERIES AND PARALLEL

2.01 Figure 13-12 shows two similar generators connected in series. The voltmeters indicate that the voltage produced by the two is the sum of the voltages produced by each generator. If the generators are connected in parallel, the voltage will be the same as of either generator alone. However, the current capacity will be increased. Thus, it is seen that the same principles apply in combining of generators as in combining of battery cells.

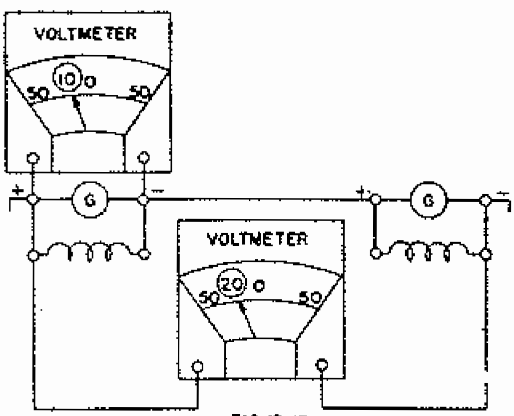


FIG. 13-12

3. PULSATING CURRENT GENERATORS

3.01 One end of the loop shown in Figure 13-13 is connected to a solid slip ring while the other end is connected to one segment of a two segment commutator. When the armature

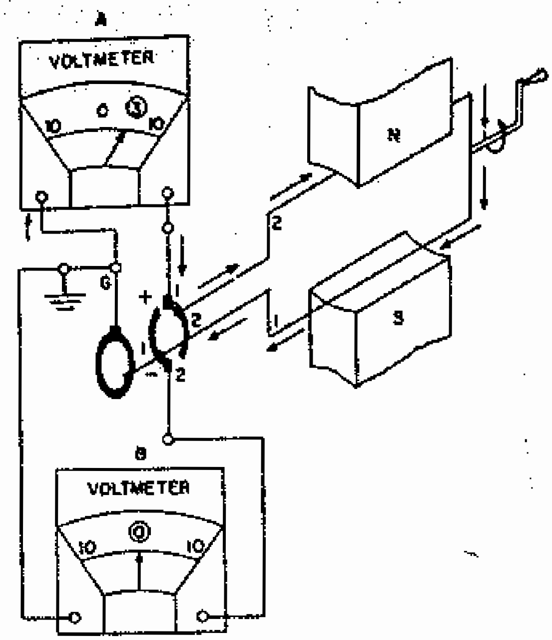


FIG. 13-13

is in the position shown a voltage is produced between the + brush and brush G, causing a current to flow as indicated by meter A, while no voltage exists between the − brush and brush G. On the other hand, when the armature is in the position shown in Figure 13-14 a voltage in the other direction is indicated between the − brush and brush G. Figure 13-15 re-

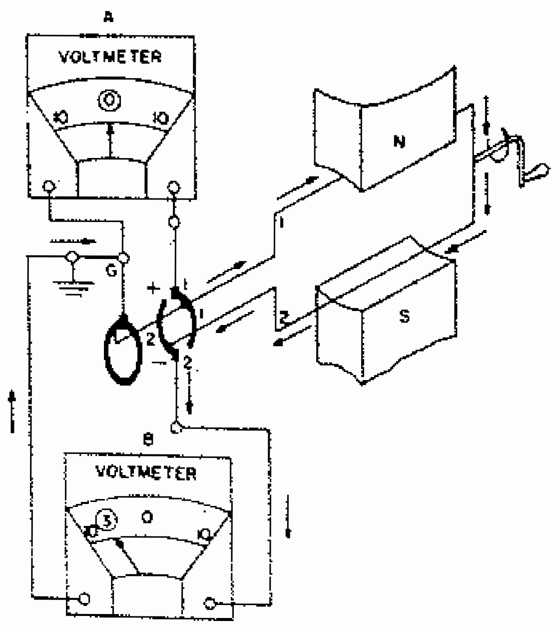


FIG. 13-14

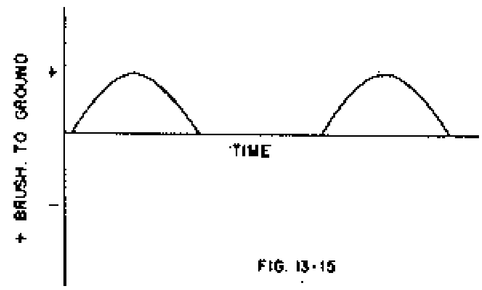


FIG. 13-15

presents the voltages between the + brush and ground when the armature is rotating steadily. This is positive pulsating current. That from the - brush is negative pulsating current, (Figure 13-16).

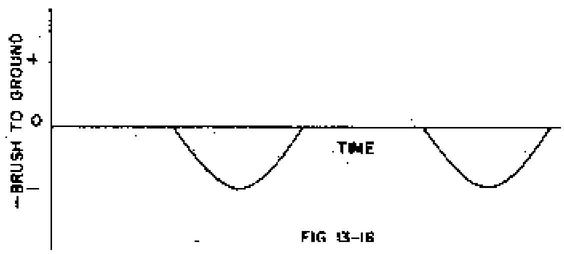


FIG 13-16

4. QUESTIONS

1. What are three faults which would reduce the voltage produced by a generator?

2. What is the purpose of a commutator?

3. What trouble would result if the series winding of a compound generator were open?

4. Why do they use more than two commutator segments in some D.C. generators?

CHAPTER XIV

CAPACITANCE

1. ELECTRON DISPLACEMENT

1.01 Like electrical charges repel each other so that one electron in space exerts a force on another. If two metal plates are connected as shown in Figure 14-1, both plates are at the same potential. If there were more electrons on plate 2 than on plate 1, the repelling force between the two groups of electrons on the plates would cause a flow of electrons to equalize the number of electrons on the two plates. However, when the key is

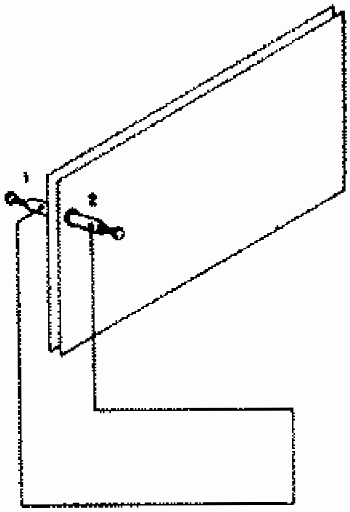


FIG. 14-1

closed, (Figure 14-2) plate 2 will be connected to the positive terminal of the battery, and the attraction of the battery removes electrons from plate 2. As these electrons move away, the repelling force between the two plates tends to decrease, so that other electrons can move from the negative terminal and accumulate on plate.1. Since plate 2 has fewer electrons than before, it is positive with respect to plate 1. Also, plate 1 has more electrons than before so it is negative with respect to plate 2. Thus, a voltage exists between plates 1 and 2. The flow of electrons can continue only until the voltage between plates 1 and 2 equals the battery voltage. Since the number of electrons or charges on the two plates is now unequal they are said to be charged.

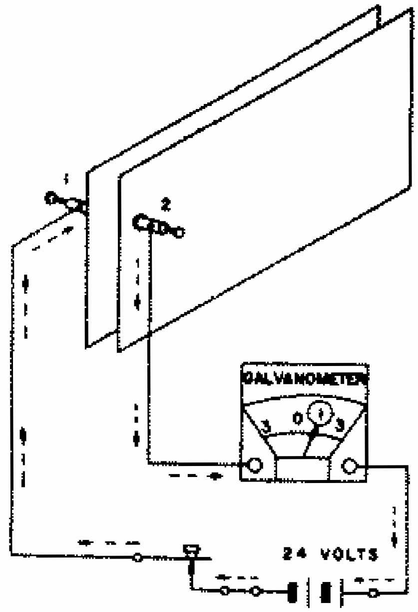


FIG. 14-2

1.02 When Key A in Figure 14-3 is closed, the needle of meter A is momentarily deflected. This indicates that the battery has caused a certain quantity of electricity to flow from one plate of the capacitor to the other over the path designated by the dotted arrows. If key A is opened, the quantity of electricity which was transferred cannot return, and we say that the capacitor is charged.

1.03 The difference of potential between the two plates may be shown to be equal to that of the battery, plate 1 being negative and plate 2 positive. If key B is now closed, the

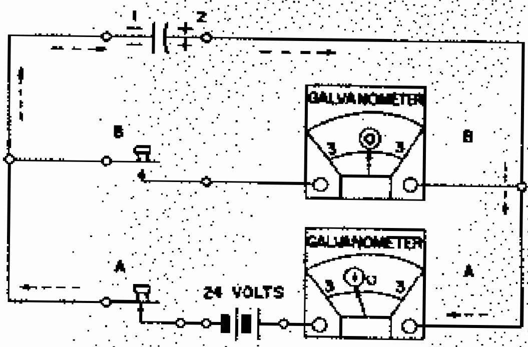


FIG. 14-3

needle of meter B will be deflected momentarily in the opposite direction from that when key A was closed, indicating that the electricity caused to flow from one plate to the other has returned. (Figure 14-4) The capacitor is now said to be discharged.

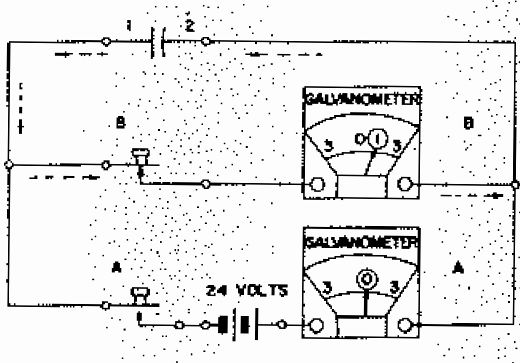


FIG. 14-4

1.04 When the switch shown in Figure 14-5 is closed as shown, the needle of the meter is deflected momentarily, as indicated by the dotted arrows. The distance that the needle is deflected is proportional to the quantity of electricity which flows. If the switch is opened, the capacitor remains charged. However, if the switch is closed in the other direction,

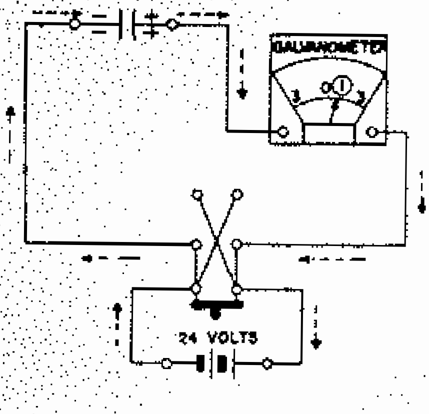


FIG. 14-5

the needle will be deflected twice as far in the other direction. (Figure 14-6) That is, the capacitor will be discharged and then charged in the opposite direction.

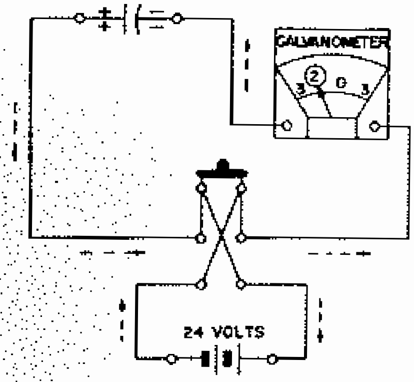


FIG. 14-6

1.05 The plates of the capacitor in Figure 14-8 are much larger than those in Figure 14-7. When the circuits to charge the capacitors are closed, meter B is deflected farther than meter A. This indicates that a greater quantity of electricity flowed in charging the large capacitor than in charging the smaller one. That is, THE QUANTITY OF ELECTRICITY WHICH FLOWS FROM ONE PLATE OF A CAPACITOR TO THE OTHER WHEN A GIVEN VOLTAGE IS APPLIED IS PROPORTIONAL TO THE SIZE OF THE PLATES.

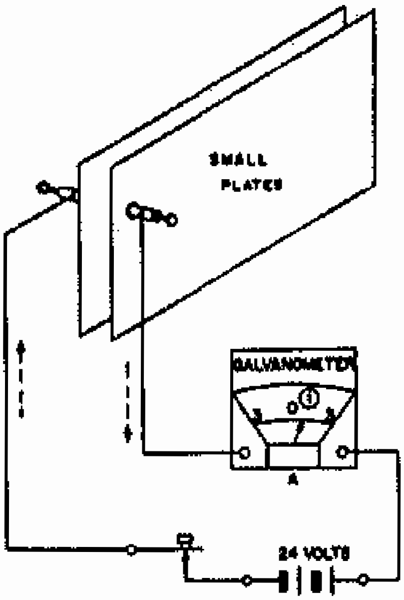


FIG. 14-7

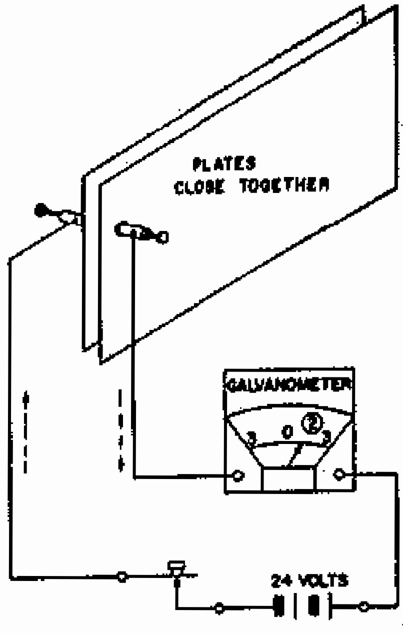


FIG. 14-9

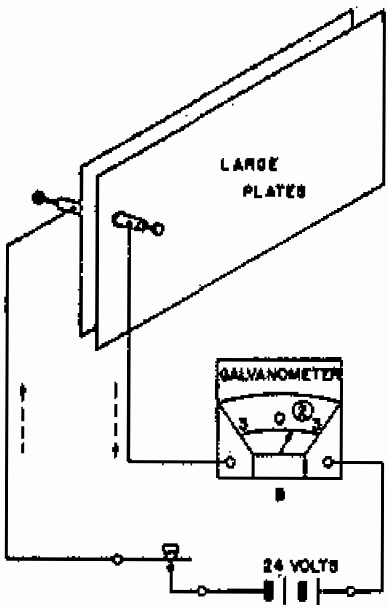


FIG. 14-8

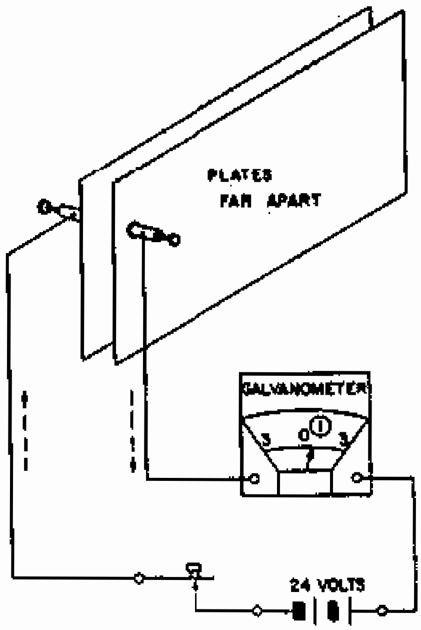


FIG. 14-10

1.06 The plates of the capacitors in Figure 14-9 and 14-10 are alike, but those of capacitor in 14-10 are father apart. When the capacitors are charged, more electricity flows in Figure 14-9 than in Figure 14-10. This shows THAT THE QUANTITY OF ELECTRICITY WHICH FLOWS TO CHARGE A CAPACITOR TO A GIVEN VOLTAGE IS DEPENDENT UPON THE NEARNESS OF THE PLATES TO EACH OTHER.

1.07 It may likewise be shown that the kind of material used as insulation between the two plates helps to determine how much electricity it takes to charge a capacitor to a given voltage. The dielectric of a capacitor is the non-conductor placed between the two plates. It may be air, or substances such as glass, mica, waxed paper or porcelain. The dielectric constant of air is unity. The dielectric constant of any material is equal to the ratio of the capacity of a capacitor using this material as a dielectric, compared to the capacity of the same capacitor using air as a dielectric. Waxed paper has a dielectric constant of from 2 to 6; therefore a capacitor using this substance as a dielectric will have from 2 to 6 times the capacity of a similar capacitor using air as a dielectric.

1.08 The capacity of a capacitor to store energy is dependent upon the physical make up of the capacitor and is not dependent upon voltage, frequency or current. There are three factors which may be varied to affect the capacity of a capacitor; the area of the plates, the distance between the plates, and the material of the dielectric. The capacity of a capacitor is directly proportional to the plate area and inversely proportional to the distance between the plates. That is, increasing the plate area increases the capacity and increasing the distance between the plates decreases the capacity.

2. UNIT OF CAPACITANCE

2.01 If only a small quantity of electricity flows when a given voltage is applied to a capacitor, that capacitor is said to have a small capacity. If, on the other hand, a large quantity flows to charge the capacitor to the given voltage, the capacitor is said to have a large capacity. Capacity is measured in units called FARADS. However, the capacity of ordinary capacitors are only very small fractions of a farad. Therefore, for the sake of convenience the capacity of a capacitor is expressed in MICROFARADS, abbreviated M.F.; the microfarad being one-millionth of a farad. The more common capacitors used in the telephone systems have capacities of about one or two microfarads.

2.02 The unit of capacity is the farad. It is defined as the capacity of a capacitor which will be charged with one coulomb of electricity when its plates are subjected to a difference of potential of one volt. The letter C, used in equations, designates farads. The farad is too large a unit for practical work in telephony and radio; therefore the microfarad which is $\frac{1}{1,000,000}$ of a farad or the micromicrofarad which is $\frac{1}{1,000,000}$ of a microfarad are used. The unit used in equations must always be in farads.

C = Farads
uf = Microfarads
uuf = Micromicrofarads

3. QUANTITY OF CHARGE

3.01 The quantity of electricity that is stored on a capacitor is determined by the formula $Q = CE$. That is, for a given capacity C of a capacitor, the quantity of electricity may be increased by increasing the applied voltage. However, if the voltage is increased to excess it will puncture the dielectric and ruin the capacitor. The voltage at which a capacitor will become punctured is known as the breakdown voltage. Capacitors are rated in both capacity and voltage.

4. PRACTICAL FORMS OF CAPACITORS

4.01 Capacitors are of various forms adapted to the purpose for which they are used. The air capacitor in which air is the dielectric, usually consists of two sets of metallic plates connected in parallel, one set being insulated from the other. This form of capacitor, whose capacitance may be varied at will, is used to a considerable extent in radio apparatus. The mica capacitor consists of sheets of tinfoil separated by thin sheets of mica. Alternate sheets of tinfoil are connected together to form a capacitor of many parallel plates. Mica capacitors frequently are used in radio sets and as standards for the comparison of electrical capacities. The paper capacitor (Figure 14-11) consists of two long sheets of tinfoil separated by two sheets of paraffined paper rolled in a compact form, and then sealed in an appropriate container. This type of capacitor is used to a large extent in telephone and radio apparatus.

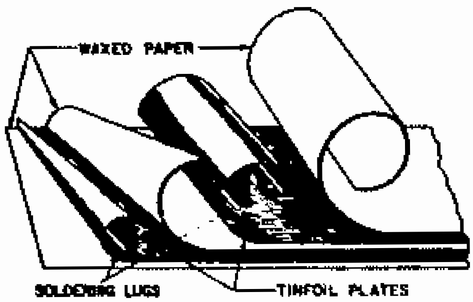


FIG. 14-11

5. CAPACITORS IN PARALLEL AND IN SERIES

5.01 The three capacitors represented in Figure 14-12 are all of the same capacity. Capacitors 1 and 2 are connected in parallel, and when the key is closed meter A is deflected twice as far as meter B. This demonstrates that two similar capacitors in parallel have twice as much capacity as one alone. If more capacitors are connected in parallel, the capacity will be further increased. That is, THE TOTAL CAPACITY OF CAPACITORS IN PARALLEL IS THE SUM OF THE CAPACITIES OF THE INDIVIDUAL CAPACITORS.

5.02 When the key in Figure 14-13 is closed, meter A is deflected only half as far as meter B. This shows that TWO SIMILAR CAPACITORS IN SERIES HAVE ONLY HALF AS MUCH CAPACITY AS EITHER CAPACITOR ALONE. If more capacitors are added in series, the capacity of the combination will be still further decreased.

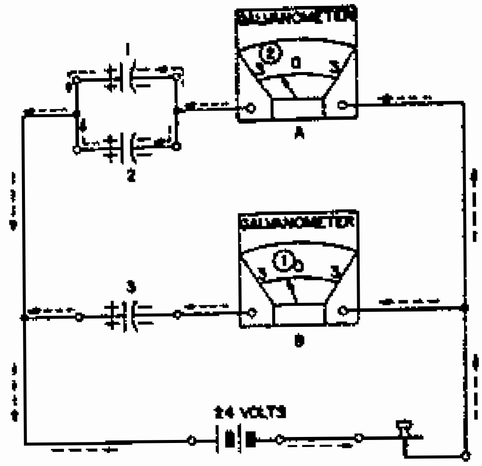


FIG. 14-12

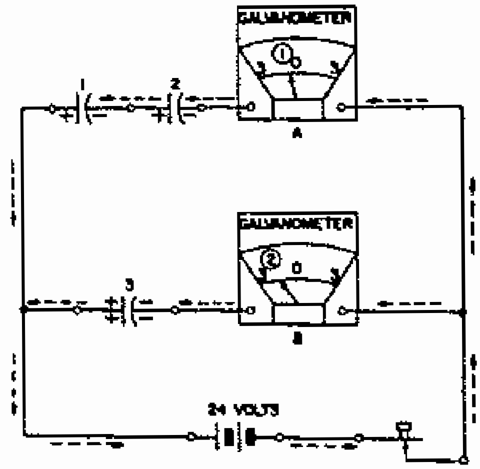


FIG. 14-13

5.03 The capacity of two or more capacitors in parallel is the sum of the individual capacities, since the effective plate area is increased.

$$C_T = C_1 + C_2 + C_3 \dots \text{etc.}$$

The capacity of two or more capacitors in series is obtained in the same manner as is the total resistance of a number of resistors in parallel. Equal charges are carried by the various capacitors in the series connection and the effect is to reduce the total capacity of the system. For several capacitors in series:

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

For two capacitors in series the above formula reduces to:

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

6. USE OF CAPACITORS TO PASS A.C. AND BLOCK AN UNCHANGING D.C.

6.01 By reference to Figure 14-2 it will be seen that a capacitor acts as an open circuit to an unchanging D.C. After the capacitor is charged no current will flow. This is because the applied potential and polarity is the same at all times. However, the plate charge will be changed in quantity only as the applied potential is increased, decreased or reversed. In short, current will flow only as a result of potential changes or reversals in a capacitive circuit.

6.02 An A.C. voltage is periodically reversing polarity and constantly changing potential. Referring to paragraph 6.01, it can be readily understood that a capacitor connected in an A.C. circuit will allow current to flow. The intensity and direction of this current will be proportional to the A.C. source.

6.03 This summary statement may be made: A capacitor will block an unchanging D.C. and allow A.C. or changing D.C. to pass.

7. QUESTIONS

1. Of what does a capacitor consist?
2. What is meant by the capacity of a capacitor?
3. Upon what three things does the capacity of a capacitor depend?
4. What is the unit of capacity?
5. Will a capacitor having a dielectric of air have a higher capacity than one having a dielectric of waxed paper if the distance between the plates of both capacitors is equal?
6. What two things determine the quantity of electricity that will flow into a capacitor when it is connected to an e.m.f.?
7. Does a charged capacitor hold its charge indefinitely?
8. Is it possible to have a perfect capacitor?
9. How is the total capacity of capacitors connected in series found?
10. How would you determine the total capacity of a circuit that had several capacitors connected in parallel?
11. Find the total capacity of a circuit which contains a .4-uf, 25-uuf, and a 200-uuf capacitor in series.
12. What would the capacity of the above circuit be if the capacitors were connected in parallel?
13. Which capacitor requires the greater quantity of electricity to charge it to a given voltage, one of ½ M.F. capacity or one of 2 M.F.?
14. Will a click be heard in the receiver when the clip is touched to the lug A in figure 14-14? Will the click be heard when the clip is removed? When the clip is touched to lug A again?

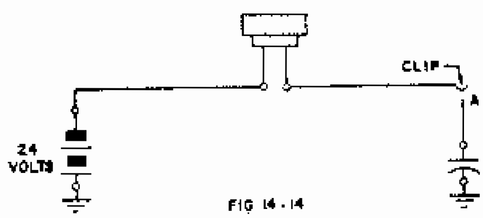


FIG 14-14

15. Will a click be heard when the end of the wire is touched to the clip in figure 14-15. Will a click be heard each time the clip is touched to the lug?

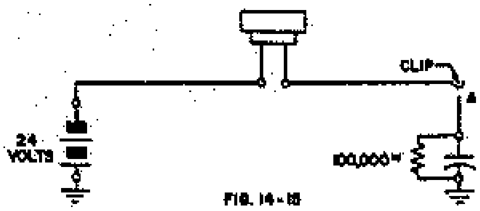


FIG. 14-15

16. What is the equivalent resistance of a capacitor in an unchanging D.C. circuit?

17. What is the equivalent resistance of a capacitor in an A.C. circuit?

18. What is the equivalent resistance of a capacitor in a circuit with changing D.C.?

CHAPTER XV

INDUCTANCE

1. Opposition To Change In Current

1.01 In an earlier discussion it was shown that when an e.m.f. is impressed on a conductor and a current made to flow through the conductor, the motion of this current of electricity produces a magnetic field of force about the conductor.

1.02 Self induction is the induction of an e.m.f. in a conductor or circuit caused by changes in the current flowing through that same conductor or circuit. As current starts to flow through a straight conductor, there is a build up of field, beginning at the center of the conductor and gradually expanding outward until the conductor itself is cut by this field. When the lines of force reach the outer edge of the conductor, they expand still farther, to the area around the conductor. During the period that the lines of force expand through the conductor they induce an e.m.f. in the conductor. This induced e.m.f. is always in such a direction that it tends to oppose any change in the current in the conductor. When the current in one turn of a coil suddenly increases, the lines of force set up around this turn will expand and in so doing will cut some or all the neighboring turns of the coil, thereby inducing in them an e.m.f., which is in the opposite direction to that of the original current. The reverse of this condition is also true, that is, when the current in this particular turn decreases the field will shrink or contract, and in so doing will again cut all the neighboring turns, but in the reverse direction. The cutting of these turns by the decreasing field induces an e.m.f. Each turn of the coil acts on other turns, thereby greatly amplifying the effect of self induction. Therefore, a coil will have much more self induction than a straight conductor. The effect can be increased many times by the use of an iron core in the coil to decrease the magnetic resistance (reluctance).

1.03 Self induction may be said to be that property of a circuit whereby it tends to oppose any change of current flow in the circuit. Self induction is electrically very similar to mechanical inertia which tends to oppose setting up motion in a body and also tends to keep the body in motion after the force causing the motion is removed. An inductive circuit acts as though it possessed inertia, that is, it resists any change and especially a sudden change in the strength of the current flowing through it.

1.04 The e.m.f. that is induced in a coil, when the current is increasing is in opposition to the applied e.m.f. Being in opposition to the applied e.m.f., this self induced e.m.f. is sometimes called back e.m.f. or counter e.m.f. (c.e.m.f.). As soon as the current reaches its maximum value and the field is steady and unchanging the c.e.m.f. will cease. However, the energy required to establish the magnetic field will be returned to the circuit when the current collapses. As the magnetic field collapses on the coil, an e.m.f. is again induced in the coil but in the opposite direction to that due to the expanding field. This induced e.m.f. will be in the same direction as the original impressed voltage, that is, in such a direction as to prolong the current flow.

1.05 The current that is caused to flow in a closed circuit by an induced e.m.f. will produce its own magnetic field, and the direction of this magnetic field will be in such a direction as to oppose the inducing field. In the case of an e.m.f. induced in a coil, by plunging a bar magnet into the coil, a north pole would be created at the end of the coil into which the north pole of the bar magnet was thrust. See Figure 15-1.

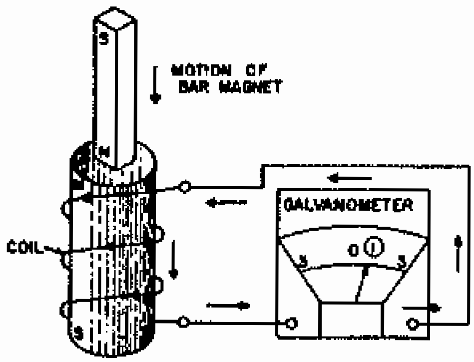


FIG.15-1

Lenz's law is very important in all electrical work. The law is stated as follows and should be memorized: In all cases of electromagnetic induction the induced magnetic field is of such direction as to oppose the inducing field.

1.06 To determine the direction of the induced e.m.f. in a coil it is necessary to label the coil with a pole that would repel the inducing pole. With this labeled pole as a factor, apply the left hand rule for determining the polarity of a solenoid, as given in Chapter X; also see Figure 15-1.

1.07 If a circuit, such as that shown in Figure 15-2, is connected with a large coil in series with an ammeter, it will be seen on opening and closing the circuit that the meter rises to its maximum and returns to zero slowly.

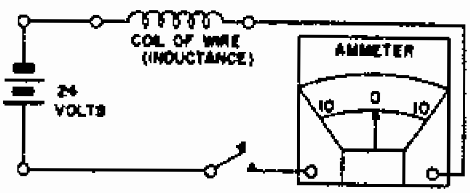


FIG.15-2

Obviously, there is something retarding the flow of current when the circuit is closed and maintaining the current flow when the circuit is opened.

1.08 In a previous discussion it was shown that when a current flows through a wire it sets up a magnetic field around the wire. The strength of this magnetic field is proportional to the current which is flowing, and the direction of the field is dependent upon the direction of the current. If the current changes in value, the magnetic field changes with it, and if the current in the conductor is alternating, the magnetic field changes in magnitude and direction with the current. For all practical purposes, the change in the magnetic field is instantaneous with the change in current.

1.09 Whenever the magnetic field surrounding a wire or coil is made to change an e.m.f. is induced (counter e.m.f.) which tends to oppose any change in the circuit. This counter e.m.f. normally written c.e.m.f. is the result of the expanding or collapsing magnetic flux field and is caused by the current flowing in the wires. To avoid confusion, take the process step by step:

a. The voltage is impressed across the coil and the current tends to flow.

b. The current flowing in the coil causes a magnetic field to build up around each loop and encompass the entire coil.

c. As the magnetic field builds up, it cuts the turns in the coil and induces an e.m.f. in each turn.

d. These e.m.f.'s are in series and additive and they oppose the applied voltage as a c.e.m.f.

e. Opposing the applied voltage, this c.e.m.f. tends to prevent the flow of current and therefore delays it.

1.10 The result is that the c.e.m.f., instead of being momentary, as in a d-c circuit when the circuit is made and broken, is continuous but varies in value like the applied e.m.f. and the current.

2. THE UNIT OF INDUCTANCE

2.01 It is common practice to refer to a coil as an inductance. The inductance of the coil is, in fact, the property which we endeavor to use when the coil is put into the circuit. Defined: Inductance is the measure of the ability of a circuit to establish a magnetic field about itself and induce a c.e.m.f.

2.02 A single straight wire has some inductance, because it sets up a magnetic field about itself which induces a c.e.m.f. A wire made into a loop will have a somewhat larger inductance, because the flux field will be concentrated within it and will be larger, thereby enabling it to induce a larger c.e.m.f.

2.03 If two or more loops are put together with the current going the same way in each, the fields of each wire will link with the others and a large strong field will be obtained in the coil. This stronger field will in turn increase the c.e.m.f., thus increasing the inductance of the coil. If an iron core is placed in the coil, so as to provide a low reluctance path for the magnetic field, the field becomes very strong and a very large c.e.m.f. will result.

2.04 Further refinements in the making of large inductances include:

a. Winding the coil tightly to cut loss of flux through leakage.

b. Providing a return path of iron to keep the reluctance of the magnetic circuit low.

c. Providing a large number of turns.

2.05 The measure of the inductance of a coil or a circuit is its ability to induce a c.e.m.f. with a change of current in the coil or circuit. This unit or coefficient is called the henry, the symbol for which is L.

2.06 One henry is that amount of inductance possessed by a circuit which enables a counter e.m.f. of one volt to be induced when the current is changing at the rate of one ampere per second.

2.07 Thus, if current changing in a coil at the rate of 5 amperes per second induces 10 volts of c.e.m.f. then the coil has an inductance of 2 henries.

3. INDUCTOR

3.01 When the transmitter diaphragm in Figure 15-3 vibrates, the electrical current flow is varied, and a work spoken into the transmitter may be heard in the receiver.

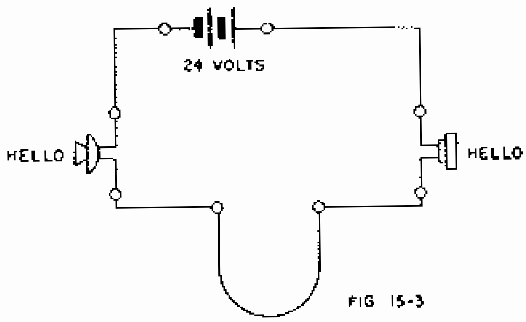


FIG 15-3

3.02 In Figure 15-4 the excess wire has been wound around an iron core. A word spoken into the transmitter is only faintly heard in the receiver. That is, when the current is increasing, the coil opposes the battery and when the current is decreasing, the coil aids the battery. Therefore, changing the resistance of the transmitter rapidly does not greatly affect the current flow. We speak of this property of a coil as SELF INDUCTION or INDUCTANCE. A coil used to prevent rapid changes or current flow in a circuit is known as a CHOKE, or INDUCTOR.

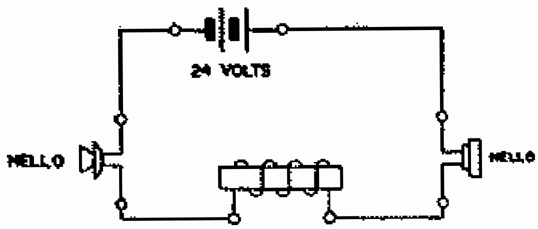


FIG. 15-4

3.03 In Figure 15-5 the relay is operated and the winding "chokes" or "retards" rapid changes in current flow so that the word spoken is faintly heard. The coil shown in

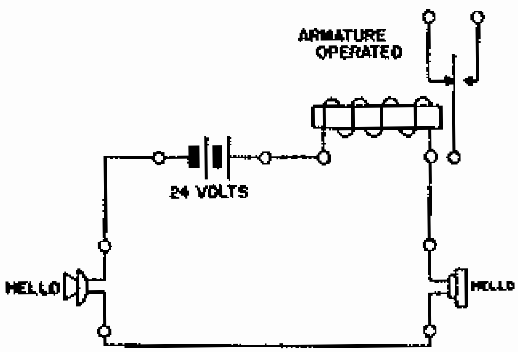


FIG. 15-5

Figure 15-6 was wound by grasping the middle of the excess wire and winding both halves of it at once. It may be seen that the current flows around the core in one direction over half of the length of wire, and in the opposite direction over the other half. There is no pull on the armature, and a word spoken into the transmitter is heard as plainly as if the wire had not been wound on the core at all. Such a winding is known as a NON-INDUCTIVE WINDING and is often represented in a circuit by this symbol, 

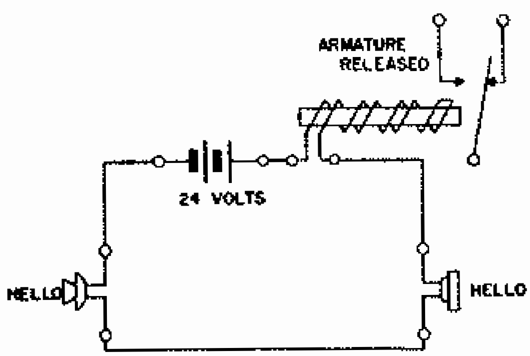


FIG. 15-6

The inductive winding and the non-inductive winding of the relay shown on the relay in Figure 15-7 are connected so that part of the total current goes through the one and the rest through the other. The current going through the inductive winding causes the armature to be pulled up, and the non-inductive path permits the transmitter to vary the current flow through the receiver. Thus the relay feature has been included in the circuit without appreciably affecting transmission.

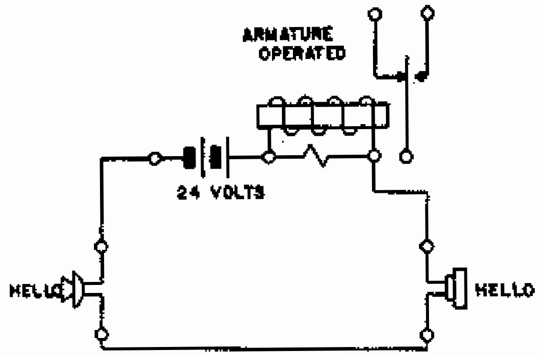


FIG. 15-7

3.04 A word spoken into the transmitter of Figure 15-8 is heard plainer in the associated receiver than a word spoken into the transmitter shown in Figure 9. This is because the TWO INDUCTORS IN SERIES HAVE MORE INDUCTION THAN EITHER INDUCTOR ALONE.

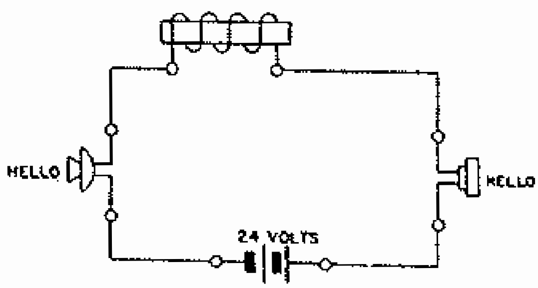


FIG 15-8

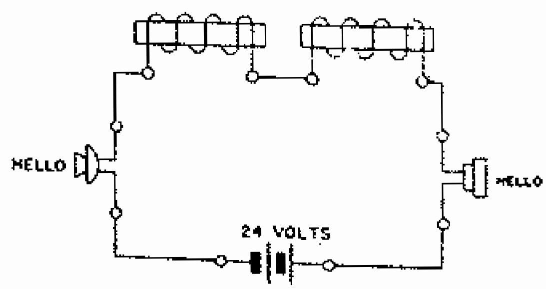


FIG 15-9

If more coils were added in series the inductance would be still further increased. However, a word spoken into the transmitter of Figure 15-10 is heard plainer in the associated receiver than in Figure 15-8. That is, TWO INDUCTORS IN PARALLEL HAVE LESS INDUCTANCE THAN EITHER INDUCTOR ALONE. Likewise, if more inductor coils are connected in parallel the total inductance would be still further reduced.

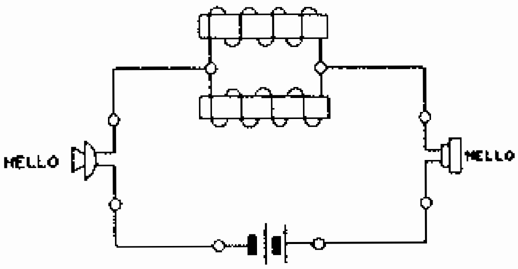


FIG 15-10

3.05 Relay (A) in Figure 15-11 has more turns of wire on it than relay (B), and consequently more self-inductance. When the key is opened, both windings tend to discharge in the directions shown by the dotted arrows, but since relay (A) produces the higher electrical pressure, relay (A) will discharge through relay (B), as indicated by the solid arrows. It may be seen that the current flow through relay (B) is immediately reversed. Thus relay (B) loses its magnetic pull immediately and releases before Relay (A).

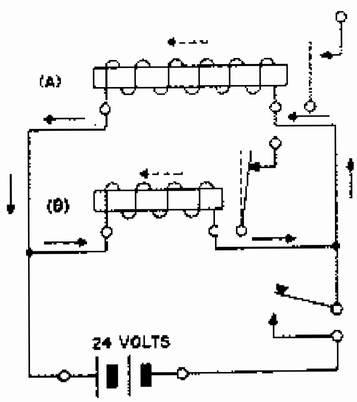


FIG. 15-11

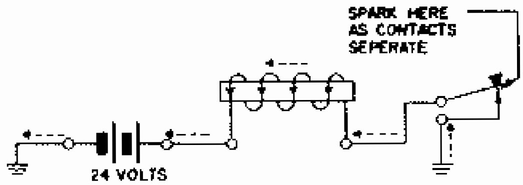


FIG 15-12

3.06 When the key in Figure 15-12 is opened, a spark may be observed between the two contacts as they separate. If a person is touching the wires on each side of the contacts, he will feel a shock when the key is opened. This is explained by the fact that the inductance tends to keep the current flowing at its former rate; and when the contacts are suddenly opened, sufficient pressure is created to force the current through the intervening gap. The coil must give up the energy stored in it while the current was building up, just as a bullet must give up the energy which it has received from the explosion of the cartridge before it will come to rest. When the key in Figure 15-13 is opened, the coil discharges its energy through the non-inductive winding, as indicated by the arrows. Consequently no spark is observed at the contacts. The current will continue to flow until all of the energy has been used up in overcoming the resistance of the circuit. Since the current flow through the inductive winding continues longer after the circuit is broken than when the non-inductive path was not provided, it takes a comparatively longer time for a relay so wound to release.

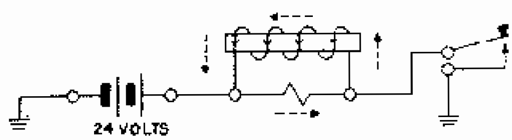


FIG.15-13

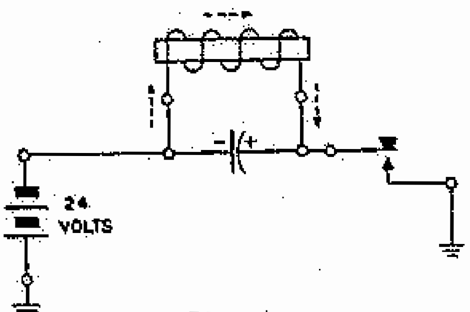


FIG. 15-14

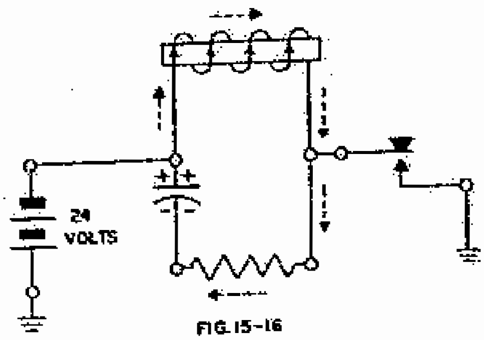


FIG. 15-16

3.07 When the circuit in Figure 15-14 is broken, the coil and the capacitor both discharge in the same direction, as indicated by the dotted arrows. The induction of the coil, however, keeps the current flowing after the capacitor is discharged, so that the capacitor becomes charged in the opposite direction. As soon as the coil discharges to the voltage of the capacitor the current flow ceases and then the capacitor starts to discharge through the coil. This current flows first in one direction and then in the other, as shown in Figure 15-15 until the energy stored in the capacitor and in the coil has been used up in overcoming the resistance in the circuit. Thus a capacitor may be used instead of a non-inductive winding or other parallel resistance to prevent a coil from discharging through a person's body or across opening contacts. By including the proper amount of resistance in the circuit, as shown in Figure 15-16, the arcing tendency may be still further reduced.

4. Inductance In Series or Parallel

4.01 Inductances can be connected in either series or parallel combinations. In a series connection the same current will flow through each inductance. Thus for a series combination of inductances, the total inductance L is equal to the sum of the individual inductances, thus:

$$L = L_1 + L_2 + L_3 + \ldots\text{etc.}$$

4.02 If two or more inductances are connected in parallel, the applied voltage will cause different currents to flow in each branch. The total current as already learned is the sum of the individual currents. Inductances in parallel can be computed as an equivalent inductance by the method that was used for combining parallel resistors,

$$L = \frac{L_1 \times L_2}{L_1 + L_2}$$

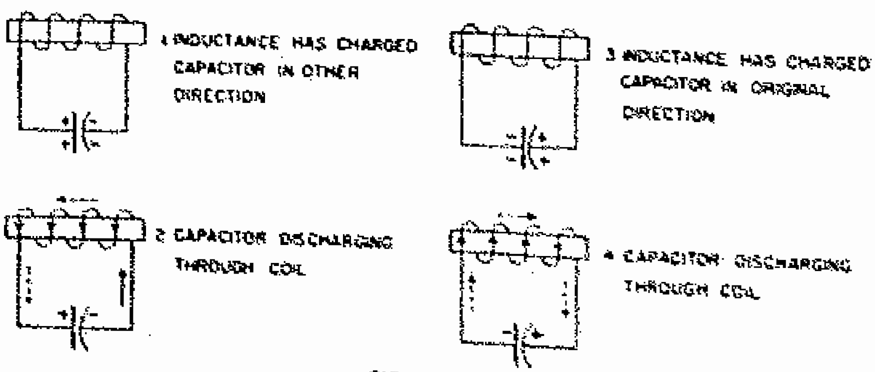


FIG. 15-15

4.03 When there are more than two inductances, the above equation can still be used by pairing off the inductances and using the equation the required number of times. Upon consideration it is seen that the method used in determining the total inductance in series or parallel is the same as was already used for resistance.

5. Inductances in D.C. and A.C. Circuits

5.01 By reference to Figure 15-1 it will be seen that an inductance offers no resistance to current flow other than the resistance of its turn of wire. That is, after the magnetic field is established maximum current will flow. This is because the applied potential and polarity is the same at all times. However, the magnetic field will be changed in quantity as the applied potential is increased, decreased or reversed. In short less current will flow as a result of potential changes or reversals in an inductive circuit.

5.02 An A.C. voltage is periodically reversing polarity and constantly changing potential. Referring to paragraph 5.01, it can be readily understood that an inductance connected in an A.C. circuit will diminish the current flow. The intensity and direction of this current will be proportional to the A.C. source.

5.03 This summary statement may be made:
An inductance will allow an unchanging D.C. to pass and diminish A.C. or changing D.C.

6. A Comparison of Inductance and Capacitance

6.01 The conception of capacitance and inductance in any telephone circuit with regard to this course will be:

A capacitor blocks an unchanging D.C. and allows A.C. or changing D.C. to pass.

A coil allows an unchanging D.C. to pass and opposes A.C. and changing D.C.

6.02 The statements in paragraph 6.01 apply only when the capacitor and coil are a part of telephone circuit design. However, if a capacitive or inductive effect is a result of circumstance rather than design the effects will be modified by the individual amount of capacity or inductance.

7. Questions

1. What is meant by inductance?

2. When two separate inductances are connected in parallel, how is the total inductance of the circuit found?

3. What are the factors determining the inductance of a coil?

4. Define the unit of inductance.

5. When two separate inductances are connected in series, how is the total inductance of the circuit found?

6. What effect does the c.e.m.f. have on the current which induces it?

7. What is the difference, if any, between self induced voltage and c.e.m.f.?

8. Of what use is a choke coil in an A.C. circuit? In a D.C. circuit?

9. What is a non-inductive winding?

10. Why is a non-inductive winding used?

11. Does an inductance or choke coil allow varying D.C. to pass?

CHAPTER XVI

TRANSFORMERS, REPEATING COILS AND INDUCTANCE COILS

1. General

1.01 One of the most important advantages of alternating current over direct current is the ease with which the transformation from a low to a high voltage, or vice versa, can be accomplished. This process is most easily effected by the means of a transformer.

1.02 A transformer is an electrical device that is placed in an a-c circuit to transfer power from one circuit to another at the same or at some other voltage. The two circuits concerned are connected inductively, by means of a common magnetic field, and not metallically, except in a few special cases.

1.03 Alternating current at a given voltage is applied to the transformer and is raised or lowered in voltage, depending upon the construction of the particular transformer. A transformer that raises the given voltage is called a step-up transformer, while a transformer that lowers the given voltage is called a step-down transformer.

1.04 For the student to properly understand the operation of a transformer it is necessary that he have a working knowledge of Induced Currents as discussed in Chapter XV; Paragraph 1.01 to 1.10.

2. Mutual Induction

2.01 Mutual induction is the production of an e.m.f. in a circuit as a result of the circuit being cut or threaded by a variable flux from a neighboring circuit. In Figure 16-1, circuit A has an e.m.f. produced in it by mutual induction, because the circuit is being cut by a varying magnetic field or flux surrounding circuit B. If circuit B is connected to a battery, the current flowing through B will cause a magnetic field to build outward and encompass the other wire A. An e.m.f. with polarity opposite to that of B, will be induced in A during the time the field is building up, because the lines of force are moving outward from B to A. If the battery is then disconnected, another momentary e.m.f. will be induced in A by the collapsing magnetic field. The polarity of the e.m.f. induced by the collapsing field in A, will be opposite to the polarity of the e.m.f. induced by the initial expansion of the field. The first effect was caused by the wire being cut by lines of force moving in an outward direction, and the second

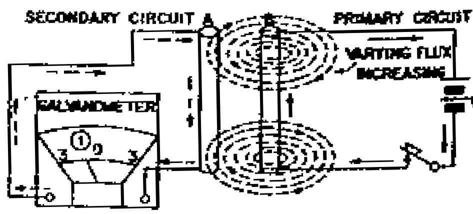


FIG. 16-1

effect was caused by the lines of force being cut by the wire while moving in the reverse direction. The second wire A has been termed the secondary circuit and the wire B which is used to create the magnetic field is called the primary circuit. Any change of current in the primary either produces an expansion or contraction, of the magnetic field about it, hence, a current of varying strength will cause the field to alternately expand and contract and induce an e.m.f.

2.02 The value of the induced e.m.f. depends on the number of lines of force cut, the number of turns of wire exposed to the field (if the wire is bent into loops), and the speed or time rate at which the lines are cut. It is thus apparent that the more rapidly the magnetic field is moved the greater will be the induced e.m.f.

2.03 The induction coil, used in telephone apparatus, operates on the principle of mutual induction. The induction coil consists of two windings of insulated wire wrapped on a core of soft iron strips. The iron core is used to reduce the reluctance of the magnetic circuit.

2.04 Mutual induction between telephone lines and parallel trolley wires or electric light and power lines often causes considerable interference, by producing noise on the telephone lines. This noise is caused by the telephone lines being within the range of constantly changing magnetic fields which surrounds the power circuit. See Figure 16-2.

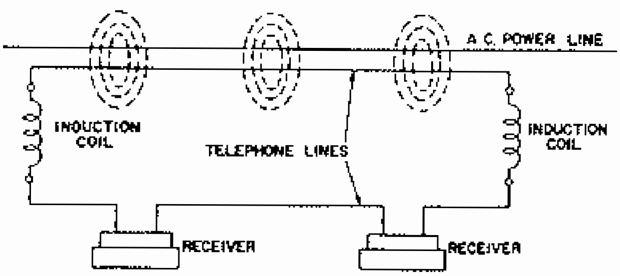


FIG. 16-2

2.05 In the study of induction it should be noted that there is absolutely no transfer of current from one circuit to the other. It is incorrect to say that the current of the secondary is induced from the primary circuit. Current can not be induced by current; only e.m.f. can be induced. The current that flows in the secondary is the result of that induced e.m.f.

2.06 A student should be very certain not to confuse magnetism and electricity as they are vastly different forces.

3. Principles of The Induction Coil

3.01 Figure 16-3 shows an iron core on which are placed two windings. Winding 1 is connected to a battery and push button in circuit 1. Winding 2 is connected to a meter in circuit 2.

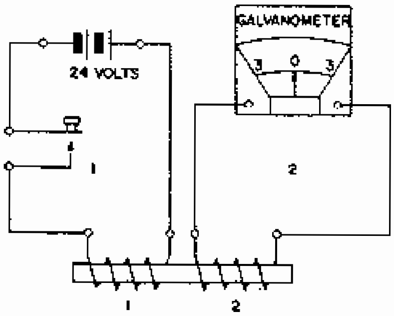


FIG. 16-3

There is no current flowing through circuit 1 because it is open at the push button. Circuit 2 is closed, but there is no current flowing through it, as shown by the zero position of the meter needle. When circuit 1 is closed at the push button, Figure 16-4, the needle of the meter in circuit 2 swings over to the right as indicated and then swings immediately back to zero point. This indicates that there was a momentary current flow. There is no further movement of the needle as long as circuit 1 remains closed. When

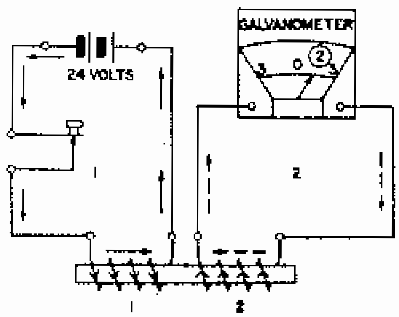


FIG. 16-4

circuit 1 is opened, Figure 16-5, the meter needle swings to the left and then returns immediately to the zero point, indicating that a momentary current flow in the other direction has occurred. There is no further movement of the needle as long as circuit 1 remains open. Placing a meter in circuit

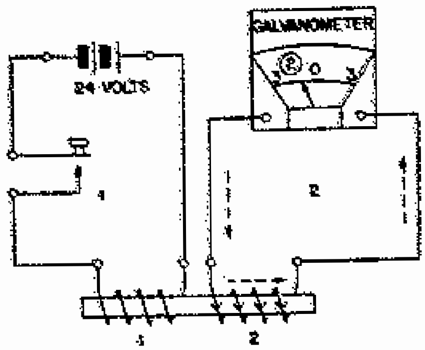


FIG. 16-5

1 which is called the primary circuit, will help to illustrate the relation between the action in this circuit and the action in Circuit 2, which is called the secondary circuit.

3.02 When the primary circuit is closed at the push button Figure 16-6, both meter needles move. The needle of meter No. 1 moves from zero to the right, as shown, and remains in this position as long as the primary circuit remains closed, while the needle of meter No. 2 swings to the right as shown and then returns immediately to the zero point. The direction of current in both circuits is shown by the arrows. It should be noticed in Figure 16-6 that the current in the secondary winding, marked Sec., is in the opposite direction from the current in the primary winding, marked Pri. When the primary circuit is opened

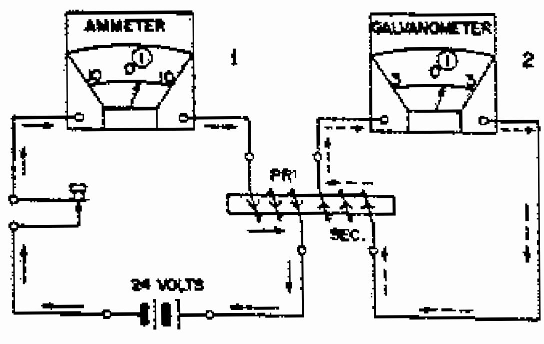


FIG. 16-6

at the push button (Figure 16-7), both needles again move. This time the needle of meter No. 1 returns to zero while the needle of meter No.2 swings for an instant to the left, and then returns to zero. The arrows show the

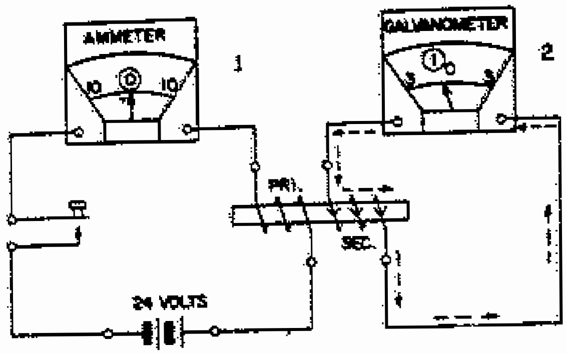


FIG. 16-7

direction of the current in the secondary circuit at the instant the primary circuit is opened. The position of the meter needles and the arrows in Figure 16-7 show that when the primary circuit is opened the current in the secondary circuit is in the opposite direction to that in Figure 16-6. Thus closing the primary circuit produces a momentary current in one direction in the secondary winding, while opening the primary circuit produces a momentary current in the opposite direction in the secondary winding.

3.03 The current used in the primary circuit in these experiments is called DIRECT CURRENT because it flows in only one direction. The current produced in the secondary circuit is called ALTERNATING CURRENT because it flows first in one direction and then in the other. The alternating current produced in the secondary circuit is known as induced current, and the apparatus used to produce it, consisting of windings of wire on an iron core, is known as an INDUCTION COIL.

3.04 These experiments show that the current in the secondary winding is caused by the action of the current in the primary winding. As the two windings are made of insulated wire, it is impossible for current from the primary winding to flow into the secondary winding, therefore, there must be some link between the two circuits by means of which energy can be transmitted from one winding to the other. This link is explained in the following experiments.

4. Induction and Magnetism

4.01 Figure 16-8 represents an induction coil circuit. The primary circuit includes a push button meter and battery. The secondary circuit includes a meter only. The induction coil is equipped with an armature as shown. The primary circuit is open at the push button and there is no current flowing in either the primary or secondary circuit, as illustrated by the zero position of the meter needles, neither is there any magnetism in the induction coil, as indicated by the armature which is in its non-operated position. Figure 16-9 shows the same

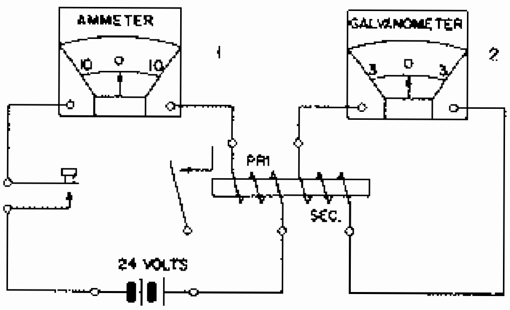


FIG 16-8

circuit just after the primary circuit is closed at the push button. The needle in meter No. 1 has moved to the position shown, while the needle in meter No. 2 has moved momentarily to the right and returned to its zero center, indicating that there was a momentary flow of current in the secondary circuit. Figure 16-10

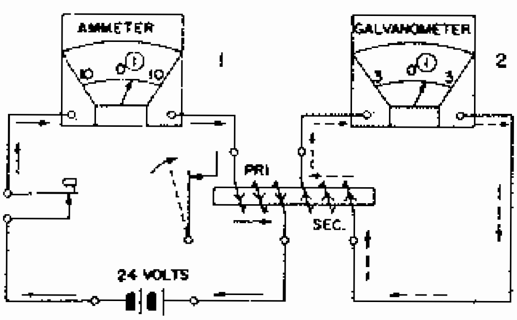


FIG. 16-9

shows the primary circuit still closed. The position of the needle in meter No. 1 indicates that current is still flowing through the primary circuit. The operated position of the armature shows that the current flowing through the primary circuit is still producing magnetism in the induction coil.

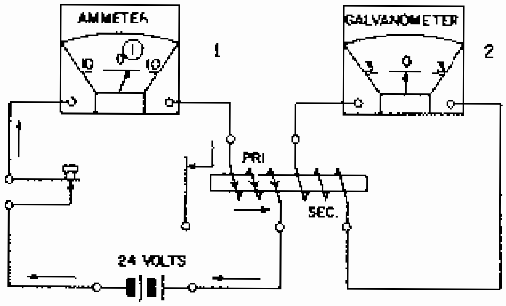


FIG. 16-10

Figure 16-11 shows the condition that exists after the primary circuit is opened at the push button. The needle in meter No. 1 has returned to its original zero position. The armature has fallen back, showing that there is no magnetism in the core of the induction coil. The needle in meter No.2 moved momentarily to the left, or in the opposite direction to its first movement, and returned to its zero center again. As long as the primary circuit remains open there will be no further flow of current in the secondary circuit.

4.02 These experiments demonstrate that the induced currents in the secondary winding are caused by magnetism because there is no other electrical link between the primary and secondary circuits.

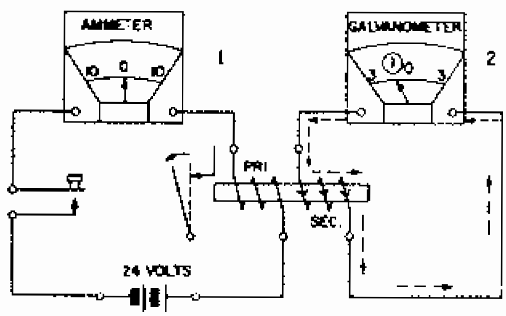


FIG. 16-11

4.03 The experiments also demonstrate THAT THE INDUCED CURRENTS IN THE SECONDARY WINDING ARE PRODUCED BY A CHANGE IN THE STRENGTH OF THE MAGNETISM. For example, there is no movement of the needle of Meter No. 2 except when the circuit of the primary winding is being opened or closed, or at the same time that there is a movement of the armature. In other words, current was produced in the secondary circuit at the time the armature was pulled up, or when the strength of magnetism was being increased. Current was also produced in the secondary circuit when the armature was released fell back, or at the time the strength of the magnetism was being decreased. There was no current flowing in the secondary during the time that the armature remained stationary in either its operated or released position; that is, when the strength of the magnetism remains constant, there is no current produced in the secondary circuit.

5. Effect of Varying Current Flow in Primary

5.01 In the experiments just illustrated the circuit of the primary winding was first closed, producing magnetism, and then opened, reducing the magnetism to zero again. The induced currents were produced by the change of variation in the strength of the magnetism. A change in the strength of the magnetism may be produced by varying the amount of current in the primary circuit instead of opening the circuit entirely.

5.02 The current may simply be reduced, thus weakening the magnetism, or it may be increased, thus strengthening the magnetism. The current flow can be varied by using a rheostat in place of a push button in the primary circuit. This is illustrated in Figure 16-12. The induction coil is indicated by two coiled lines, representing two windings of wire placed close together. The iron core is shown as two vertical lines between the two coiled lines. When the rheostat arm is in the position shown, the resistance

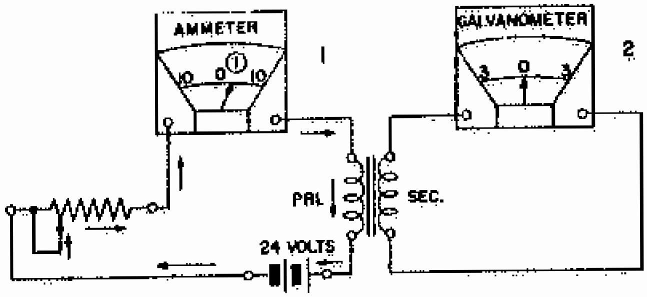


FIG. 16-12

in the primary circuit is high and the amount of the current is low. As the current is low, the magnetism it produces in the iron core will be weak. The position of the needle of meter No. 2 indicates that there is no current flowing in the secondary circuit. In Figure 16-13 the same circuit is shown. The crooked arrow indicates that the rheostat arm is being moved to the right. While the rheostat arm is moving, the current flow is increasing. This means that the strength of the magnetism in the coil is also being increased, and the needle of meter No. 2 moves to a position at the right of zero. The needle remains in this position as long as the rheostat arm is in motion and is being moved at the same rate. If the rheostat arm becomes stationary so that the primary current is no longer being increased, the needle No. 2 will drop back to zero. No further movement of either meter needle takes place until the rheostat arm is moved again. Figure 16-14 shows the effect

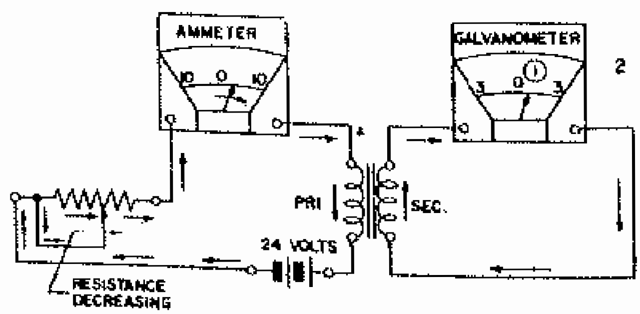


FIG. 16-13

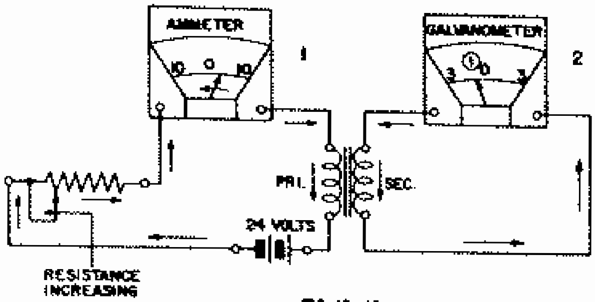


FIG. 16-14

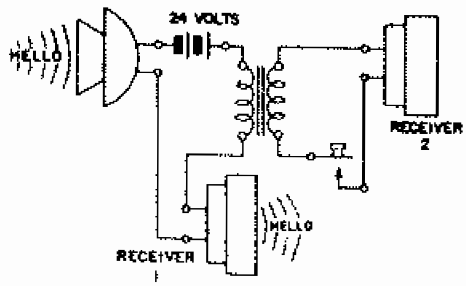


FIG. 16-15

of moving the arm back toward the left. The primary current is being reduced, and the magnetism weakened. The needle of meter No. 1 moves gradually back to the position it occupied in Figure 16-12 due to the reduction of current in the primary circuit. While the rheostat arm is moving, thus reducing the primary current and consequently the strength of the magnetism, the needle of meter No. 2 takes the position shown at the left of zero. If the rheostat arm stops, the primary current will remain steady and the needle of meter No. 2 will return to the zero point.

5.03 These two experiments show that there is a current induced in the secondary winding only while the rheostat arm is in motion; that is, while the amount of current in the primary winding is being varied. This is another way of showing that the induced current results from a change in the strength of the magnetism. IF THE STRENGTH OF THE PRIMARY CURRENT IS SUCCESSIVELY INCREASED AND DECREASED THE SECONDARY CURRENT IS ALTERNATING AS IN THE EXPERIMENTS WHERE THE PRIMARY CIRCUIT WAS OPENED AND CLOSED.

5.04 A word spoken into the transmitter of Figure 16-15 is faintly heard in receiver I. This is explained by the fact that the primary winding of the induction coil acts like a retard coil and opposes any fluctuation of the current through itself. However, when the secondary circuit is closed a word spoken into the transmitter is distinctly heard in receiver I and also in receiver 2. (Figure 16-16). This indicates that CLOSING THE SECONDARY CIRCUIT MODIFIES THE RETARDING EFFECT OF THE PRIMARY WINDING.

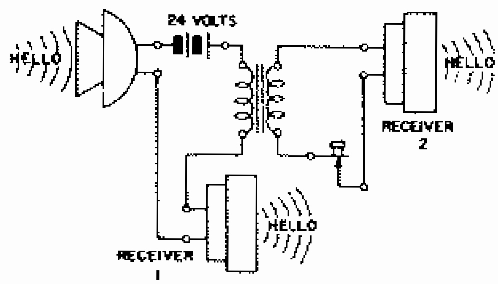


FIG. 16-16

5.05 The two pairs of line wires shown in Figure 16-17 are parallel and close to each other for considerable distance. A word spoken into the transmitter may be heard to some extent in receiver 2 as well as in receiver 1; that is, the varying of the current flow in pair 1 induces an alternating current in pair 2, just as a fluctuating current in the primary winding of an induction coil induces an alternating current in the secondary winding. In

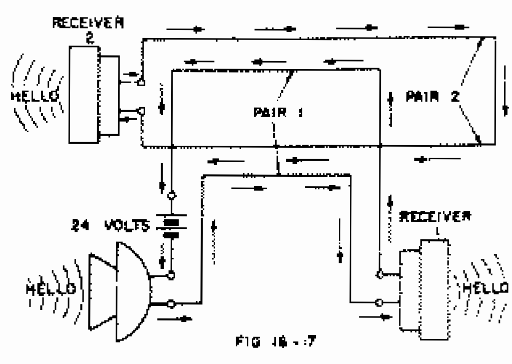


FIG. 16-17

Figure 16-18 the conductors of pair 2 are interchanged at their midpoint and there is no crosstalk. This may be explained as follows: Suppose that the current flow in pair 1, Figure 16-17 is increasing in the direction indicated by the arrows, then an E.M.F. is being induced in pair 2, as indicated by the arrows. However, if the conductors of pair 2 are crossed back and forth, as in Figure 16-18, the E.M.F.'s induced in the various sections of pair 2 neutralize each other so that no current flows.

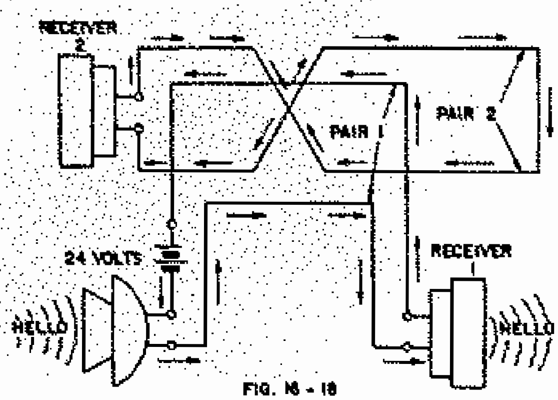


FIG. 16 - 18

6. Transformer Construction

6.01 A transformer consists essentially of two insulated coils, known as the primary and secondary windings, wound over a closed iron magnetic circuit. A simple schematic diagram of a transformer is shown in Figure 16-19. In the manufacturing process many refinements are added to the simple transformer, to increase its efficiency. The purpose of the closed iron magnetic circuit is to insure that most of the magnetic field set up by the a-c supply in the primary coil, will cut the turns of the secondary winding and induce an e.m.f. in this winding with as little loss as possible.

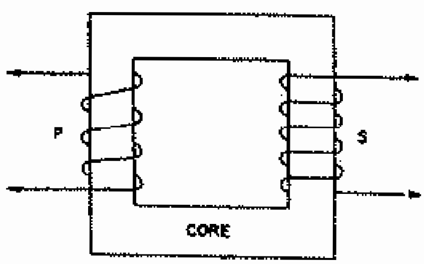


FIG. 16-19

6.02 The e.m.f. induced in the secondary will depend upon two things, namely, the number of turns in the secondary and the strength of the magnetic field produced by the primary. However, the field strength of the primary depends upon the number of turns in the primary and the voltage applied to it. Therefore, the e.m.f. induced in the secondary of a transformer depends upon the voltage applied to the primary and the turns ratio between the primary and the secondary windings.

6.03 Thus if there were twice as many turns in the secondary as were in the primary, the transformer would step up the voltage to twice the applied voltage. Similarly, if the transformer has half as many turns in the secondary as in the primary, the transformer would step down the voltage to half the applied voltage. The following formula can be used to express the relation between the turn ratio and the voltage:

Secondary or output voltage = Turn ratio x primary or input voltage

$$E_s = \frac{N_s}{N_p} \times E_p$$

E_p is primary voltage, E_s is secondary voltage, N_p is primary turns and N_s is secondary turns.

6.04 For example: Could a transformer that has an applied voltage of 110 volts with 2310 turns on the primary and 210 turns on the secondary be used to run a small electric train using 10 volts?

Thus: $N_p = 2310$, $N_s = 210$, $E_p = 110$, Find E_s

$$E_s = \frac{N_s}{N_p} \times E_p = \frac{210 \times 110}{2310} = 10 \text{ volts.}$$

The answer would be "Yes".

7. Current Relationship and Transfer of Power

7.01 A transformer does not generate power, but merely transfers it from one circuit to the other. Any voltage change due to the transfer, means an inverse change in the current values to maintain the balance in power between the two circuits, assuming the transformer 100% efficient. Therefore, the power supplied to the transformer must equal the power drawn from it or,

$P_p = E_p \times I_p$ $\qquad P_s = E_s \times I_s$

Where P_p = Primary Power
P_s = Secondary Power
E_p = Primary Voltage
E_s = Secondary Voltage
I_p = Primary Current
I_s = Secondary current
N_p = Number of turns in the Primary
N_s = Number of turns in the Secondary

Therefore, the relationship of the primary and secondary currents, to the turn ratio, will be just opposite to the relationship of the primary and secondary voltages to the turn ratio. Where the voltage relation is;

$E_s : E_p :: N_s : N_p$ (direct proportion), the current relation is;

$I_s : I_p :: N_p : N_s$ (inverse proportion).

7.02 Thus a transformer will increase the voltage at the expense of the current in the secondary, or increase the current at the expense of the voltage. Examples of this are the ignition coil with high voltage low current output, and the arc welder with low voltage high current output.

7.03 From the above equation, it should be seen that the current in the secondary circuit controls the current in the primary circuit. That is, if the resistance of the secondary circuit is decreased, thus increasing the current flow in the secondary circuit, the current flow in the primary circuit would also increase, or if the resistance of the secondary circuit is increased, decreasing the current flow in the secondary circuit, the current flow in the primary would also be decreased. Therefore, the current flow in the primary circuit is governed by the load across the secondary circuit, and the greater the load, (less resistance in the secondary), the greater the current flow in the primary circuit.

8. Loading

8.01 If the secondary is short-circuited, the primary acts as if it were short-circuited, and if the secondary is opened the primary acts as if it were opened. The reason the primary circuit acts as if it were open when the secondary is open, is due to its high inductance and may be explained as follows:

Since induced e.m.f.'s are always opposite to the inducing e.m.f. the secondary voltage of a transformer must be opposite to the primary voltage. In an inductive circuit, the c.e.m.f. developed is opposite to the applied e.m.f. Therefore, the c.e.m.f. and the secondary voltage must be together as they are both opposite to the applied e.m.f. With the secondary voltage producing no current flow, and no magnetic field to oppose the magnetic field of the primary circuit, the c.e.m.f. in the primary circuit is thus at a maximum when the secondary circuit is open. In an inductive circuit when the c.e.m.f. is at a maximum the current flow is at a minimum therefore the current flow in the primary is at a minimum when the c.e.m.f. is at its maximum. Suppose the secondary circuit were closed so that a current would flow. This would produce a magnetic field that would oppose the magnetic field produced by the primary circuit, therefore the effective field would be reduced and the c.e.m.f. would in turn be reduced. A greater current flow in the primary would be the result of this reduced c.e.m.f.

8.02 A study of Figure 16-20 will show that the greater the current flow in the secondary, the greater is the field produced by the secondary and the greater the secondary field the smaller will be the primary field, as the two fields are bucking each other. Therefore, the c.e.m.f. will be smaller, and as it is this c.e.m.f. that limits the current flow in the primary circuit, the primary current will increase when c.e.m.f. is reduced.

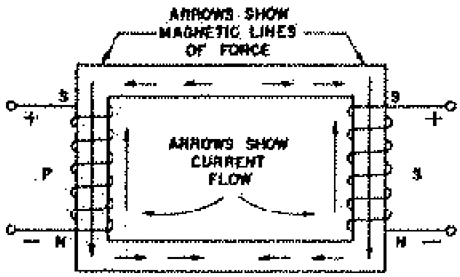


FIG. 16-20

9. Transformer Losses

9.01 Transformers are not 100% efficient. They will not transfer energy from one circuit to another without energy losses occurring. There is some resistance in both the primary and secondary coils, and the current in passing through these resistances produces heat, which represents a certain amount of energy loss, commonly called copper losses. All of the lines of force produced by the primary coil do not cut the windings of the secondary coil. Therefore, some of the magnetic field of the primary is not used in inducing the e.m.f. in the secondary. This represents a loss, as the coupling is less than unity (100%). The iron core, which is a metallic conductor in the magnetic field of the primary, has currents (eddy currents) induced in it, and since the iron is a high resistance conductor these currents cause the core to heat. This causes an additional loss in the transformer. All of these losses must be supplied by the primary source of power and the power they consume is not available at the secondary of the transformer. Large transformers, however, are very efficient, over 90 percent of the input power being transferred to the secondary circuit.

9.02 Eddy currents are those currents which are induced in masses of metal, whenever the metal is moved in a magnetic field or when the field moves through the metal. These currents are always in such a direction as to oppose the motion producing them (Lenz's Law). These currents are usually of relatively small intensity but may be enormous. They also involve an I^2R loss which may be considerable. Since eddy currents tend to flow at right angles to the direction of flux the resistance of their path and the intensity of their e.m.f.'s can be reduced by laminating the metals in which they tend to flow. Laminating is done by constructing cores in layers of thin strips of metal, approximately .01 to .03 inches in thickness, each layer insulated by paint or enamel. A laminated core offers a much higher resistance to the flow of eddy currents than a core of solid construction. All large volumes of metal that are subject to considerable eddy current loss are laminated.

9.03 Another loss occurring in transformers is that caused by the continual changing of the poles in the core of the transformer. We know that energy is required to line up the molecules in a piece of iron or steel, to produce a permanent magnet or an electro-magnet. It is also obvious that energy would be required to shift these molecules around, if it were desired to demagnetize it. Furthermore, it would again require energy to remagnetize the metal with poles opposite to those originally produced. In all of these changes a certain friction would develop between the molecules that would make their movement somewhat difficult. This friction in movement is called hysteresis. Hysteresis then, is molecular friction. More work is necessary to reverse the magnetism of a piece of hard steel than is required to reverse the magnetism of a soft piece of iron of the same dimensions. The amount of work increases as the reluctance of the material increases. When the flux of a magnetic circuit reverses many times a second, the hysteresis loss becomes of consequence, though it is usually very small as compared with output of the apparatus. This power lost by hysteresis or molecular friction appears as heat and serves no useful purpose. In constructing magnetic circuits that are subject to hysteresis loss, great care is exercised to select grades of iron that have low hysteresis loss; that is, those that have low hysteresis coefficients or constants so that the losses in them maybe maintained at a minimum. The best annealed transformer sheet steel (silicon steel) has a hysteresis constant of .001 as compared to cast iron which has a hysteresis constant of .016. Obviously, the silicon steel is best suited for transformer or armature cores.

9.04 Transformer losses are minimized as follows:

a. Resistance losses are reduced by using low resistance copper windings.

b. Core design and size will determine the amount of flux leakage.

c. Eddy currents are nearly eliminated by using laminated steel for cores.

d. Hysteresis losses are reduced by the use of silicon steel.

10. Transformer Types

10.01 Depending upon the use for which they are intended, transformers are designed in many types.

10.02 Open core transformers are quite common in the form of induction coils installed in field and some desk type telephones. The familiar ignition coil is also an open core transformer with a high step up ratio. In an open core transformer the core is usually a straight bundle of iron wire or laminations with the magnetic circuit completed through the air.

10.03 Most low loss transformers are of the closed core type. In the newer type telephones, the induction coils are appearing as closed core transformers. All power transformers are of the closed core type and some of them have more than one magnetic path.

10.04 Auto-transformers are transformers with a single winding and hence do not separate the load circuit from the power source. Usually the entire winding is used for the primary, and certain predetermined portions of the winding are used to satisfy the secondary voltage requirement. There is a direct metallic connection between the primary and secondary circuits. Figure 16-21 illustrates a closed core auto-transformer.

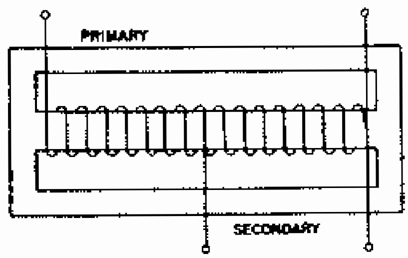


FIG. 16-21

10.05 Air core transformers are used when small coupling is desired between the primary and secondary circuits, as in some radio work. Air core transformers have no iron cores to cause hysteresis losses, which in the higher radio frequencies would be prohibitive.

10.06 Variable inductors are merely transformers. One type uses a sliding contact on a winding. The inductance of this type is varied by moving the slider, and in effect it is a variable ratio auto-transformer.

Another type has a movable coil within the primary coil and the bucking or aiding action of the inner coil varies the inductance of the primary coil. Variable inductors are used to limit the current in a-c circuits without power loss in a resistor.

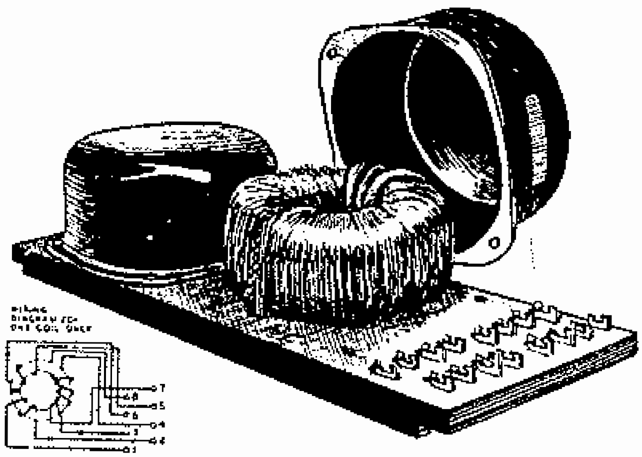
11. Repeating coils and Induction Coils

11.01 Repeating coils and induction coils are terms used to designate certain types of telephone transformers. A telephone transformer is generally called a repeating coil when it has a low ratio of transformation, and is not used in connection with vacuum tubes, where the terms input transformer and output transformer are used. An induction coil is the special name given to certain types of repeating coils which generally are associated with telephone sets and use either the straight core or shell type of construction.

11.02 According to their mechanical construction, repeating coils may be of the toroidal shell, or straight core type.

11.03 The core of a toroidal type of repeating coil consists generally of a ring of silicon steel laminations, or pressed permalloy dust rings. The windings are uniformly applied to this circular core by means of a special winding machine in which a circular shuttle threading through the center of the core is used to hold the wire which is wound on the core by means of a motor driven annular part of the machine. After the finished coil has been impregnated to make it moisture-proof, which is usually effected under vacuum after a baking period, it is sealed or potted with rosin into a pressed steel cup of a cast or sheet iron case. This cover makes the coil crosstalk proof and provides a protection against mechanical injuries.

11.04 When the steel cup is used, the coil is generally mounted on a wooden base which is slotted on the underside so that the lead-in wire may be placed in these slots and ~~connected~~ to terminal clips on the end of the board. Repeating coils of the 75 and 77 types are examples of this type of construction. Figure 16-22 shows a 75 type repeating coil, consisting of two coils on a common wooden base. The cover has been removed from the front coil to show the construction.



SCHEMATIC DRAWING
FOR ONE COIL ONLY

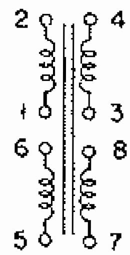


FIG. 16-22
75 TYPE REPEATING COIL

11.05 The cast or sheet iron case as a housing for the coil is used on repeating coils of later design, such as the 62, 74 and 93 types. These coils are intended for relay rack mounting and are made in either single or double units. The windings terminate at a phenol fibre terminal strip in front of the case, or so soldering terminals in the rear. See Figure 16-23.

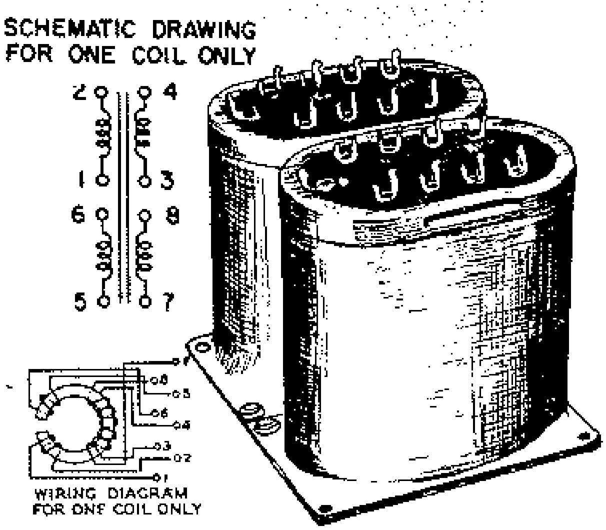


FIG. 16 - 23
62 TYPE REPEATING COIL

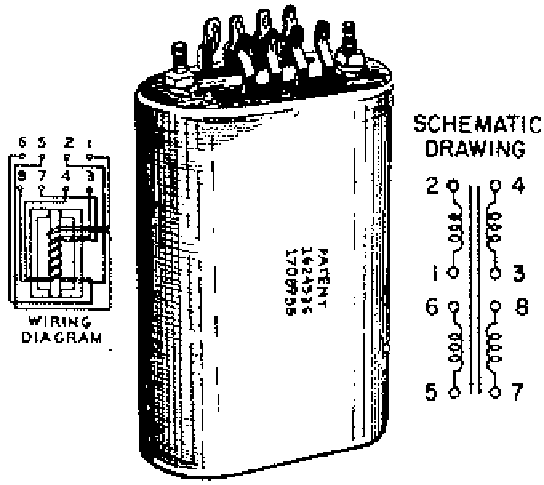


FIG. 16 - 25
94 TYPE REPEATING COIL

11.06 The core of a shell type repeating coil consists of silicon steel or permalloy laminations of various shapes similar to those shown in Figure 16-24. A number of these laminations are riveted together, forming butt joints when assembled. Two brackets and screws are used to hold the parts together. The windings

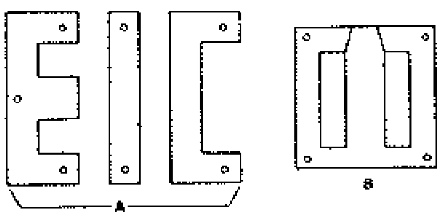


FIG 16 - 24
TRANSFORMER LAMINATIONS

are generally on a spool which fits over the center leg of the core. The 94 and 120 type repeating coils are examples of this type of construction. See Figure 16-25.

11.07 Another type of lamination shown in Figure 16-24 is also used for some repeating coils and a number of input and output transformers. This type is slitted on one side so that the center leg may be passed through the form wound coil. In assembling such a core, the slitted part is alternately placed on one or the other side of the coil.

11.08 Shell type repeating coils are generally enclosed in a sheet iron case suitable for relay rack mounting, with terminals on the mounting side.

11.09 The straight core type of repeating or induction coil has an open magnetic circuit core of silicon steel strips. The windings are brought out to terminals attached to the spoolhead. Examples of this type of construction are the 62, 63 and 72 type induction coils and 20 and 110 type repeating coils. See Figure 16-26.

11.10 Another example of the straight core type of construction is found in the 103 type repeating coil where a laminated core and cross-talk proof cover, similar to that of an "H" type relay is used. Repeating coils

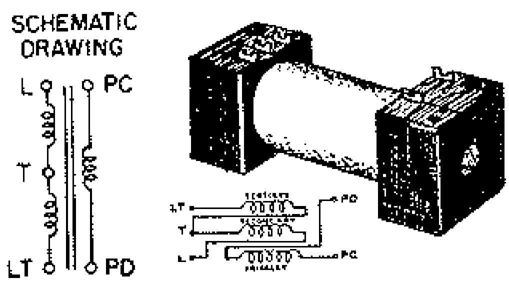


FIG. 16 - 26
62 TYPE INDUCTION COIL

of this type can be mounted interchangeably with flat type relays or 40 type resistances.

11.11 A shell type induction coil used in operator's telephone circuits is shown in Figure 16-27. It is enclosed in a rectangular metal case lined with steel for crosstalk shielding purposes. Induction coils of this type mount like relays and replace the old open type on new installations.

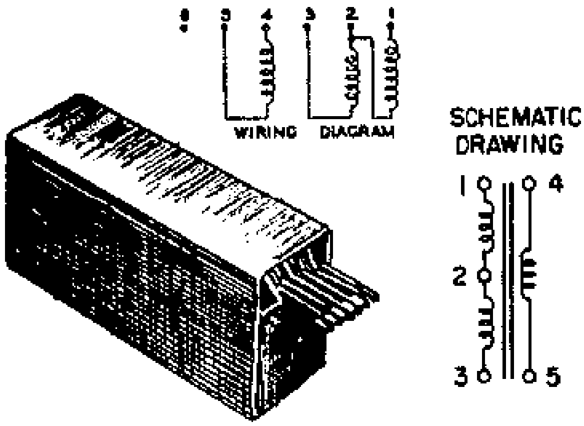


FIG. 16-27
178 TYPE INDUCTION COIL

11.12 In general, most repeating coils may be classified as battery supply repeating coils and phantom repeating coils. Battery supply repeating coils are, next to the subscriber's induction coil, the most commonly used transformer in the telephone plant. One of these coils is used in every conversation between two subscribers in the same common battery office, while two are necessary when the subscribers are in different offices. They are called battery supply coils because the direct current, which is necessary for the operation of the transmitter, is fed through the winding of these coils. Repeating coils are necessary to prevent the battery from short-circuiting the voice frequency currents passing from one subscriber to another.

11.13 Phantom repeating coils are used in the telephone plant to obtain an additional telephone channel or phantom circuit for two pairs of conductors known as side circuits. By this means three conversations are carried by four wires, thereby making a saving in the number of wires required for telephone service.

12. Shielding

12.01 Transformers, repeating coils and induction coils are normally shielded to protect them from stray magnetic fields. Interferring magnetic fields are found where numerous pieces of electrical equipment are grouped together. To control these fields shielding is used.

12.02 Soft iron may be used to protect an object from magnetic lines of force, by placing the object in the center of a circle formed by soft iron. Any magnetic lines of force, near this combination will take the path of least reluctance through the iron circle, therefore not disturbing the object. From this example a statement can be made to the effect that soft iron may be used to distort a magnetic field. Any substance that offered less reluctance to the magnetic lines of force than air could be used for the same purpose but not as efficiently as soft iron.

12.03 The principle of shielding against stray magnetic fields is illustrated in Figure 16-28. Shielding is used to confine a magnetic field as well as exclude.

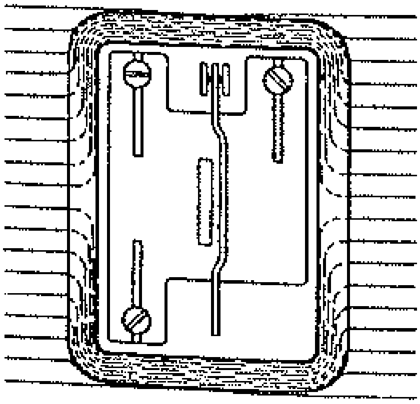


FIG. 16-28

12.04 Another type of shielding used is the electrostatic shield. This shield is used to prevent capacitive coupling between adjacent windings of relays transformers or induction coils.

12.05 This shield normally consists of a thin non-magnetic metal.

13. Questions

1. What is the purpose of a transformer?
2. Of what does a transformer consist?
3. Is the ratio between primary and secondary voltage the same as the ratio between primary and secondary turns?
4. When the secondary is open, what limits the current flow in the primary circuit?
5. Is it possible to have the secondary voltage lower than the primary voltage?
6. What is done in a transformer to reduce the power loss due to eddy currents?
7. What is done in a transformer to reduce the effects of hysteresis?
8. Can the power taken from the secondary ever exceed the input power?
9. If a certain transformer has a primary e.m.f. of 1000 volts and an output of 50 volts, how many turns of wire are there on the primary for each of the 200 turns on the secondary?
10. What type of transformer has a single winding?
11. Name four things that cause transformer losses.
12. What controls the current flow in the primary circuit of a transformer?
13. If the key in Figure 16-29 is held closed, will the armature of the relay continue to be attracted?

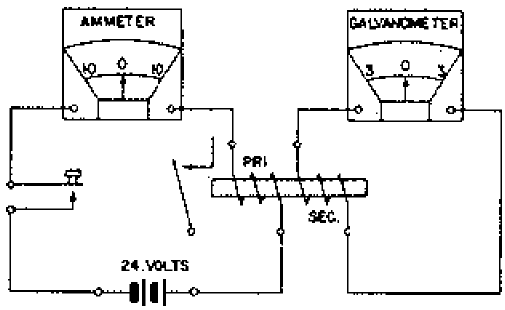


FIG. 16 - 29

14. Will both meters show a reading the instant the key is closed?
15. If the key is held closed, will both meters show a reading?
16. What is a repeating coil?
17. What material makes a good magnetic shield?
18. Give two reasons for shielding an object.
19. Name two types of shielding.

CHAPTER XVII

TELEPHONE TRANSMITTERS

1. Rheostat Analogy

1.01 Figure 17-1 shows a rheostat, a device consisting of a piece of wire having considerable resistance wrapped around a bakelite ring, and a metal arm with a bakelite handle. The arm may be turned so that it will make contact with any turn of the wire. The symbol for a rheostat is shown in Figure 17-2.

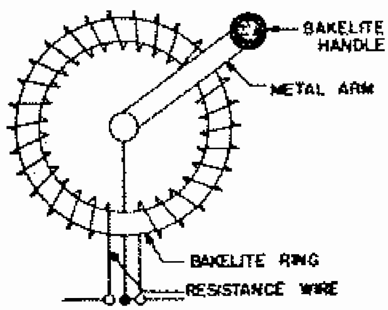


FIG. 17-1

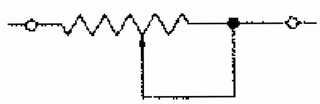


FIG 17-2

1.02 In the circuit represented in Figure 17-3, the arm is well to the right so that the current has to flow through a considerable length of the resistance wire. On the other hand Figure 17-4 represents the arm well to the left so that the current flows through only a short length of the wire. The meters indicate that much more current flows in the latter case than in the former. Devices whose resistance may be adjusted to control current flow are known as RHEOSTATS. The one shown above is of a common type.

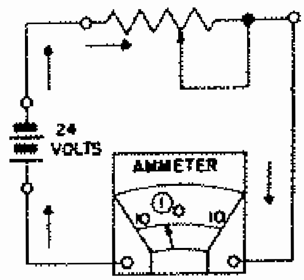


FIG. 17-3

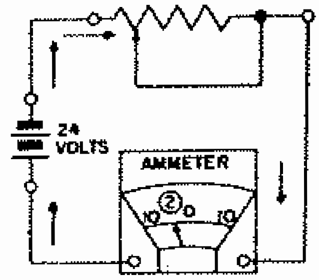


FIG. 17-4

1.03 The telephone transmitter is another type of rheostat. Figure 17-5 shows the essential parts of a transmitter, and Figure 17-6 shows these parts assembled. In Figure 17-7 the transmitter is shown connected in a circuit.

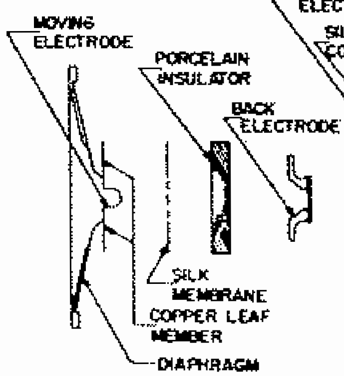


FIG 17-5

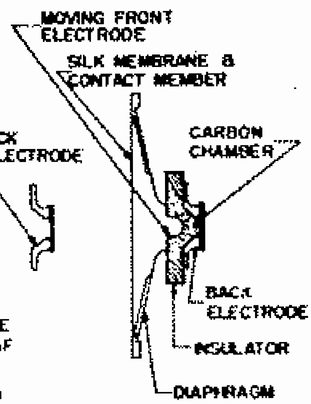


FIG 17-6

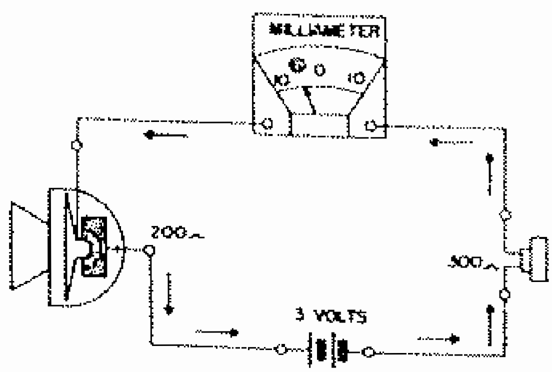


FIG. 17-7

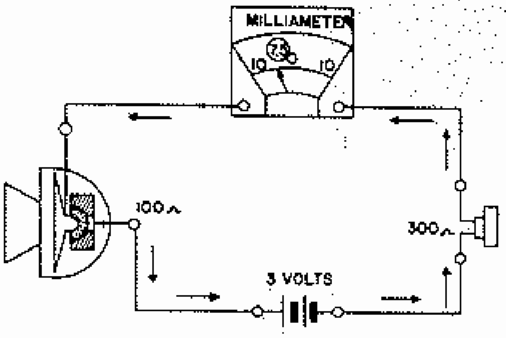


FIG. 17-8

1.04 If the diaphragm is moved inward as in Figure 17-8, the pressure on the carbon granules is increased, thereby lowering their resistance and permitting more current to flow. On the other hand, if the diaphragm is moved outward, as in Figure 17-9, the pressure on the granules is decreased so that their resistance is increased.

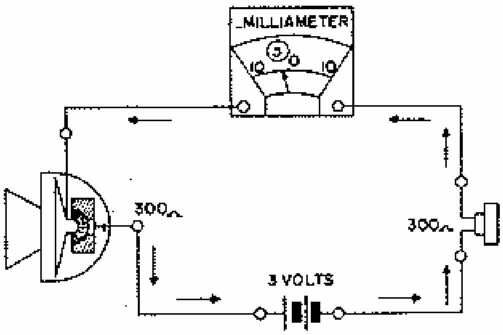


FIG. 17-9

When a word is spoken into the transmitter, the diaphragm vibrates in unison with the speakers vocal organs. This results in the resistance of the transmitter being varied accordingly. In turn, the varying or "modulated" current flow through the receiver causes the receiver diaphragm to vibrate in unison with the transmitter diaphragm and reproduce the word spoken. (Figure 17-10).

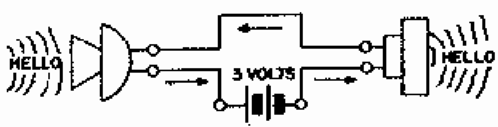


FIG. 17-10

2. Summary

2.01 From the foregoing it is evident that for the proper operation of a telephone transmitter an adequate battery supply is necessary.

2.02 Currents and subsequent voltages resulting from the transmitter action in a telephone circuit must always be considered as varying D.C. Therefore, by the use of suitable transformers (induction coils) the transmitter voltages may be stepped up, stepped down, or matched to various other units in the telephone plant.

3. Questions

1. How does a rheostat control current flow?

2. Why must the sheet metal used for transmitter diaphragms be thin?

3. Why is a transmitter battery supply necessary?

4. If the varying voltages resulting from the operation of a telephone transmitter, are impressed on the primary of a transformer what would result in the secondary properly terminated?

CHAPTER XVIII

TELEPHONE RECEIVERS

1. Magnetic Operation

1.01 Figure 18-1 shows a permanent horse-shoe magnet with its poles near the center of a thin sheet iron metal disc, known as a diaphragm. Figure 18-2 indicates that the pull of the magnet causes the diaphragm to bend down. In Figure 18-3, the permanent magnet has been replaced with two coils. When the circuit is open the diaphragm is straight, but when current flows through the coils in either direction, it is bent down.

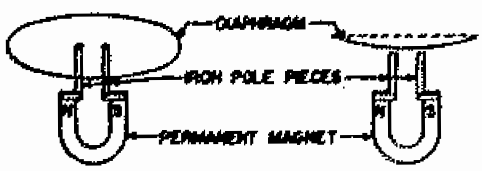


FIG. 18-1 FIG. 18-2

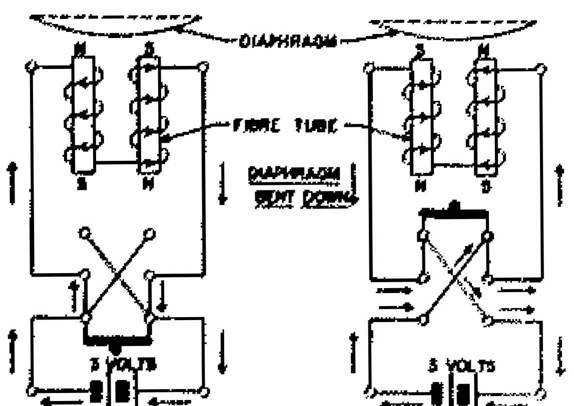


FIG. 18-3

Figure 18-4 shows the coils around the ends of the permanent magnet.

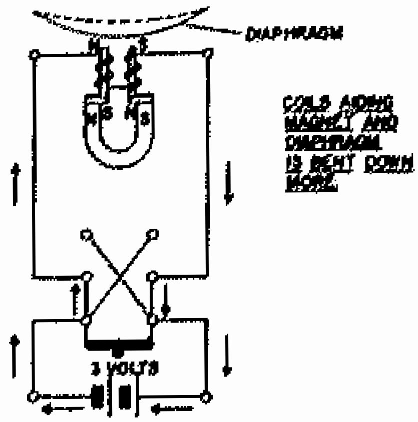


FIG. 18-4

1.02 Current is now flowing in such a direction that the coils tends to strengthen the permanent magnet and the diaphragm is bent down more. However, when the current flows in the other direction the coil tends to create poles opposite to those of the permanent magnet. (Figure 18-5) This partially neutralizes the effect of the permanent magnet so that the diaphragm is allowed to straighten out more than when no current is flowing.

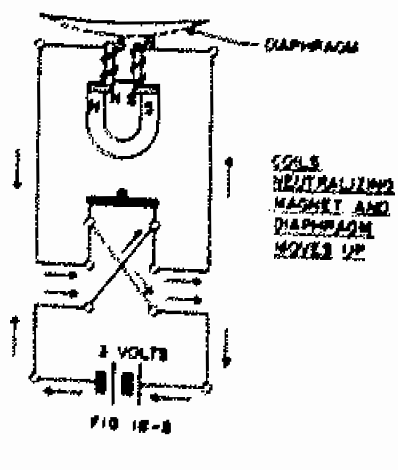


FIG. 18-5

1.03 The combination of diaphragm, permanent magnet, and coils just described comprise the essential elements of the telephone receiver. It will be noticed that WHEN CURRENT FLOWS THROUGH THE COILS IN ONE DIRECTION, THE PULL ON DIAPHRAGM IS INCREASED; BUT WHEN THE CURRENT FLOWS IN THE OTHER DIRECTION, THE PULL IS DECREASED.

1.04 The moment the key in Figure 18-6 is closed, the pull on the diaphragm produces a loud click. Likewise, when the circuit is broken a similar click is produced. (Figure 18-7)

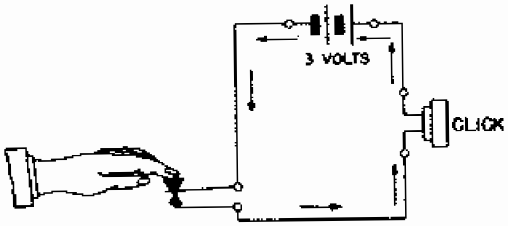


FIG. 18-6

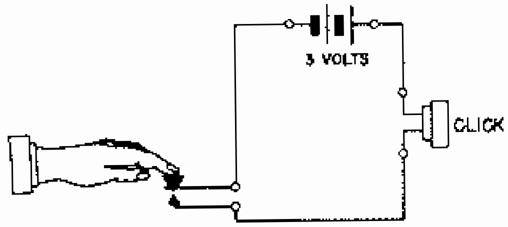


FIG. 18-7

1.05 Figure 18-8 shows a transmitter, receiver, and battery in series. When the transmitter diaphragm bends inward the current flow is increased. This increases or decreases the pull on the receiver diaphragm so that its curvature is changed accordingly.

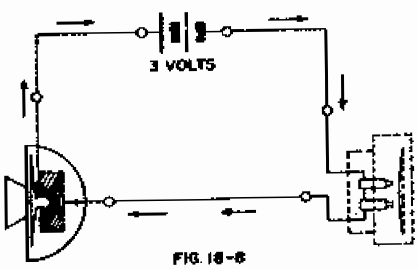


FIG. 18-8

When the transmitter diaphragm moves outward, the current flow is decreased and the receiver diaphragm moves in the other direction. (Figure 18-9)

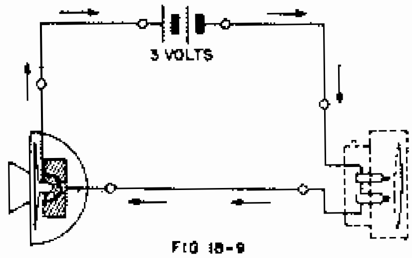


FIG. 18-9

1.06 When a word is spoken into the transmitter shown in Figure 18-10, the diaphragm vibrates in unison with the speaker's voice. This current is varied accordingly so that the receiver diaphragm is caused to vibrate in unison with the transmitter diaphragm, thus reproducing the sound of the speaker's voice. If two transmitters and two receivers are included in the circuit, two people can talk to each other. (Figure 18-11)

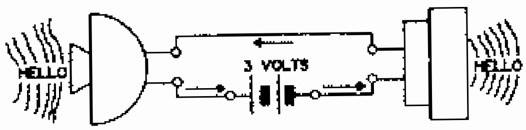


FIG. 18-10

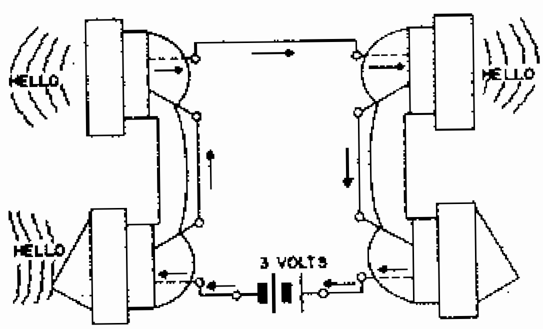


FIG. 18-11

2. Summary

2.01 In the preceeding paragraphs the receiver unit has been shown directly connected to the transmitter battery supply. In actual practice however, the receiver is connected in the telephone circuit by means of a transformer (induction coil). This is done to avoid excessive current flow through the receiver.

2.02 In the same sense that the transmitter generates varying D.C. voltages which may be more efficiently utilized by the use of transformers, the receiver has been designed to operate from varying voltages impressed by the secondary winding of a transformer (induction coil).

3. Questions

1. What are the three essential elements of a telephone receiver?

2. If current flows through the coils of a receiver and the diaphragm pull is increased, what will happen to the diaphragm if the current flows in the other direction?

3. Will the diaphragm of a receiver bend, if the current flow through the coils are increased or decreased?

CHAPTER XIX

PRINCIPLES OF VOICE TRANSMISSION

1. General

1.01 This chapter covers the general transmission features of a series telephone circuit, local battery telephone circuit, common battery telephone circuits and principles of anti-sidetone. These circuits involve the basic concepts discussed in previous chapters.

2. Simple Series Telephone Circuit

2.01 Figure 19-1 illustrates a simple series telephone circuit. Normally this circuit is not used for telephone transmission. However it does serve to illustrate the basic principles involved.

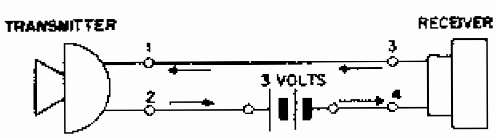


FIG 19-1

2.02 Since all circuits must be analysed in two ways, D.C. wise, (statically), and A.C. or changing D.C. wise (dynamically) we will first analyse this circuit D.C. wise. The D.C. equivalent circuit for Figure 19-1 is shown in Figure 19-2. It can be seen that the transmitter is represented as a rheostat and the receiver as a fixed resistance. The receiver may be represented as a fixed resistance (not an inductance) because this is a D.C. circuit at rest. This static (at rest) D.C. circuit analysis will enable us to calculate if necessary, the total current flowing.

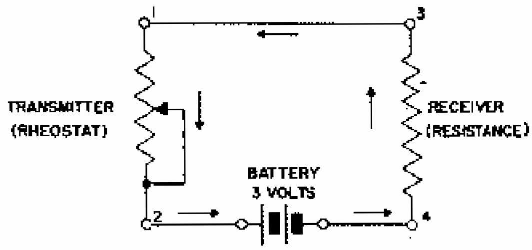


FIG. 19-2

2.03 In order to consider the circuit dynamically (in motion) it is necessary to use a changing D.C. or A.C. equivalent circuit (Figure 19-3). The transmitter is represented as a rheostat and the receiver as an inductance. The receiver is represented as an inductance because this is a pulsating D.C. circuit. However, the inductive effect is negligible by the design of the receiver. Speech, causing resistance changes in the transmitter results in current changes in the receiver. Current changes in the receiver result in changing voltage drops across the receiver. The transmitter and battery may be considered a pulsating D.C. generator with its output across terminals 3 and 4. The voltage output of the transmitter is being directly impressed across terminals 3 and 4 of the receiver and the voltage variations of the transmitter will cause corresponding voltage variations across the receiver. In this circuit the receiver and transmitter are directly coupled to one another.

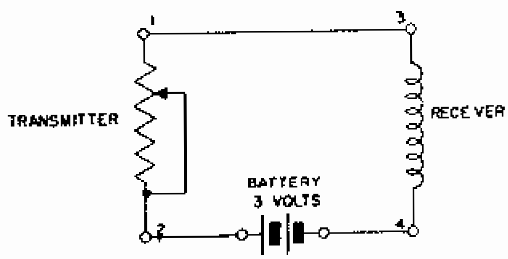


FIG 19-3

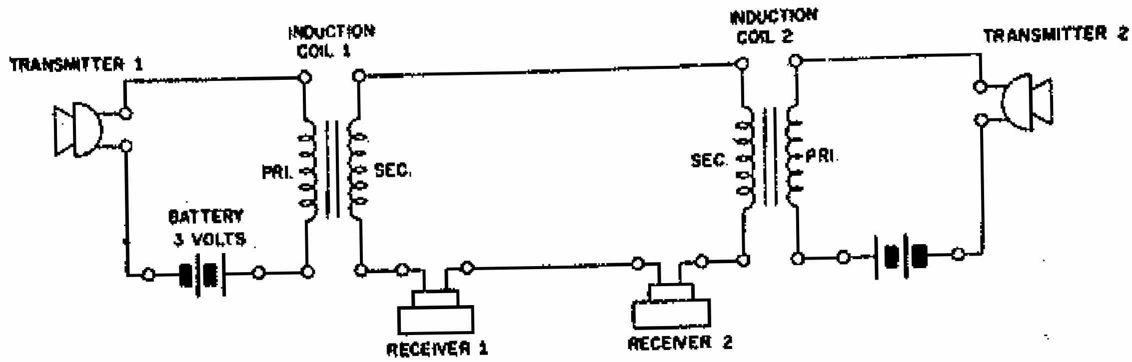


FIG. 19-4

3. Local Battery Telephone Circuit

3.01 Figure 19-4 illustrates a local battery telephone circuit. This circuit gets its name from the fact that the battery supply to each transmitter is local. The dynamic circuit equivalent of Figure 19-4 is shown in Figure 19-5. A dynamic circuit analysis of Figure 19-5 is as follows:

(a) The voltage variations of transmitter 1 are impressed across the primary of induction coil 1 when the transmitter functions.

(b) Transformer action takes place from the primary to the secondary of the induction coil 1 thereby impressing voltage variations across receiver 1, receiver 2 and the secondary of induction coil 2 in series.

(c) The voltage variations impressed across the receivers cause them to function.

(d) The voltage variations impressed across the secondary of induction coil 2 result in voltage variations across transmitter 2 which serve no useful function. From the above dynamic analysis it can be seen that if a person talks into transmitter 2 he can be heard in receivers 1 and 2. The induction coils in this circuit prevent D.C. from flowing in the receiver circuit. This local telephone circuit is sometimes used for private service but is not used in regular telephone service.

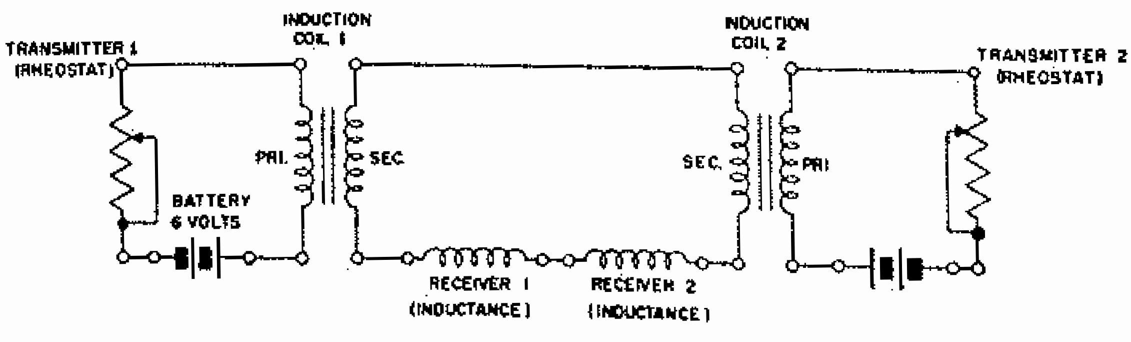


FIG. 19-5

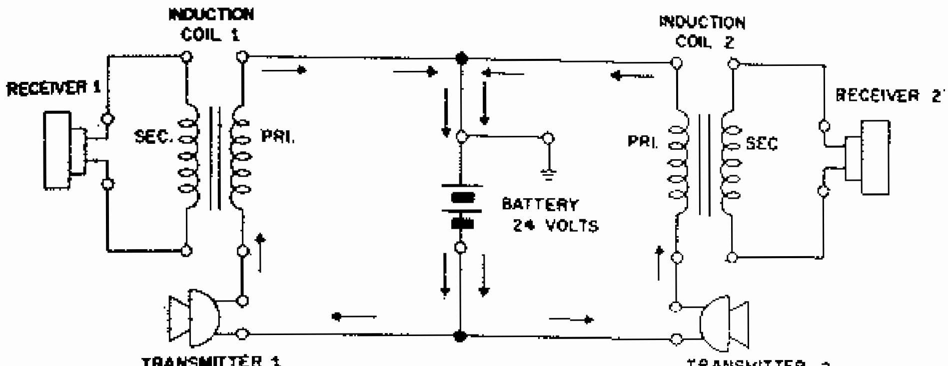


FIG 19-6

4. Common Battery Telephone Circuits

4.01 The common battery telephone circuit is used for regular telephone service and as its name implies, has its D.C. source, a common battery for all instruments.

4.02 A common battery telephone circuit is shown in Figure 19-6. It can be seen from the D.C. circuit analysis that proper transmitter current is flowing in the transmitters. However, a dynamic circuit analysis (Figure 19-7) shows that a short-circuit exists across the two instruments circuits because the common battery is assumed to offer zero resistance. Transmission in Figure 19-7 is then impossible.

4.03 In order to overcome the short-circuit existing across the two instrument circuits as shown in Figure 19-7, two resistors R_1 and R_2 may be installed as shown in Figure 19-8. A dynamic circuit analysis of Figure 19-8 is as follows:

(a) When transmitter 1 is functioning voltage variations are impressed upon the primary winding of induction coil 1, resistor R_1 and resistor R_2 in series.

(b) Transformer action takes place from the primary of induction coil 1 to the secondary thereby impressing voltage variations upon receiver 1 which results in sound in the receiver.

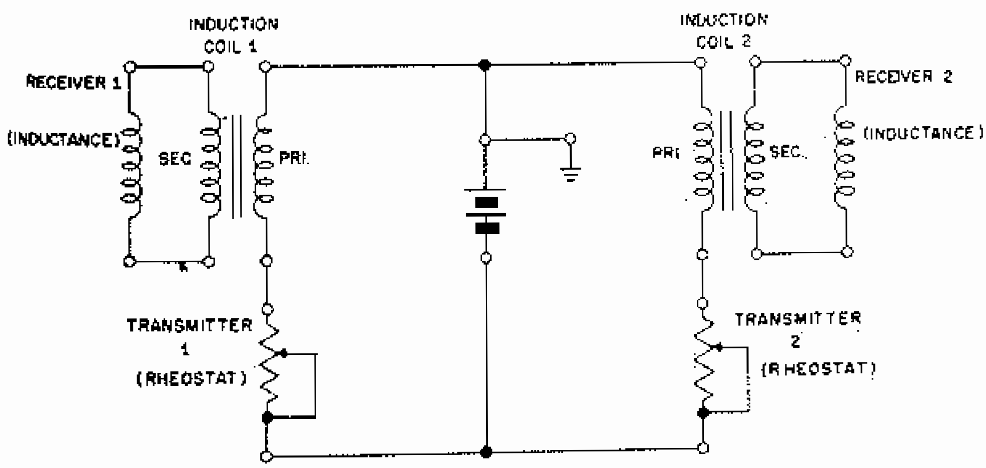


FIG 19-7

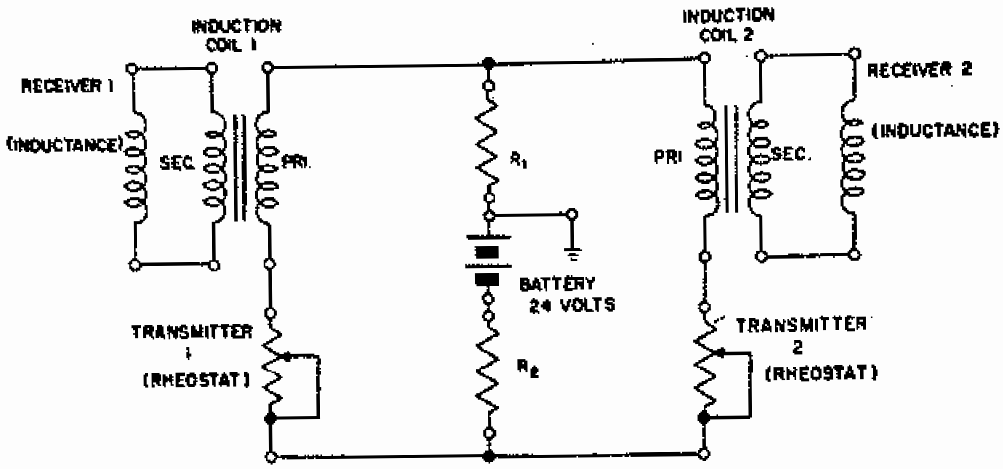


FIG. 19-8

(c) Voltage variations across the resistors R_1 and R_2 together are impressed upon transmitter 2 and the primary of induction coil 2.

(d) Transformer action takes place from the primary to the secondary of induction coil 2 thereby impressing voltage variations upon receiver 2 which results in sound in the receiver.

(e) The voltage variations across transmitter 2 serve no useful purpose.

From the above dynamic analysis complete transmission takes place from transmitter 1 to receiver 2. It can be seen that if a person talks into transmitter 2 he can be heard in receivers 1 and 2. The instrument circuits in Figure 19-8 are coupled by resistors R_1 and R_2 and the instrument circuits are said to be resistor coupled. Normally resistor coupling is not used for telephone transmission.

4.04 One of the three common battery telephone circuits now in use is shown in Figure 19-9. This circuit is normally used for P.B.X. service. A dynamic circuit of Figure 19-9 is shown in Figure 19-10. The dynamic circuit analysis of Figure 19-10 parallels that of figure 19-8. However, the shunt path of resistors R_1 and R_2 together is eliminated by using inductor coils 1 and 2. As a inductor coil blocks A.C. and changing D.C., the removal of this shunt path affords better overall transmission. Another advantage of connecting inductor coils in the circuit is to block the D.C. generator's changing D.C. from the instrument circuits. A dynamic circuit analysis of Figure 19-10 is as follows:

(a) When transmitter 1 is functioning voltage variations are impressed upon the primary of induction coil 1, the primary of induction coil 2 and transmitter 2 in series.

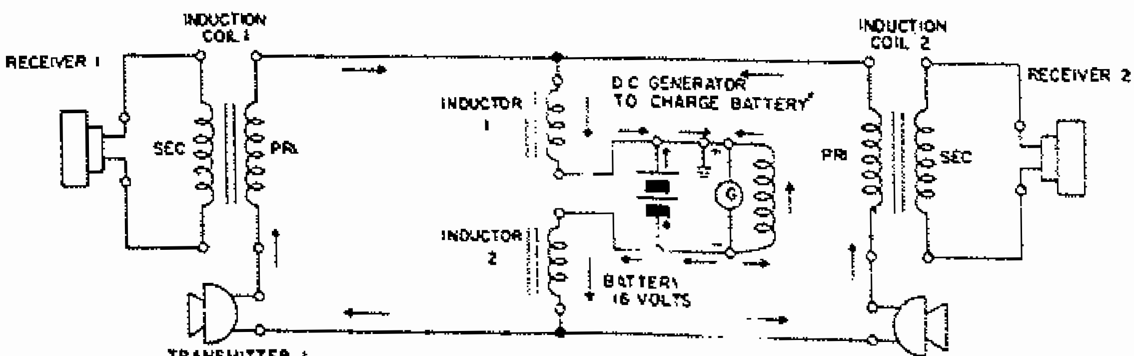


FIG. 19-9

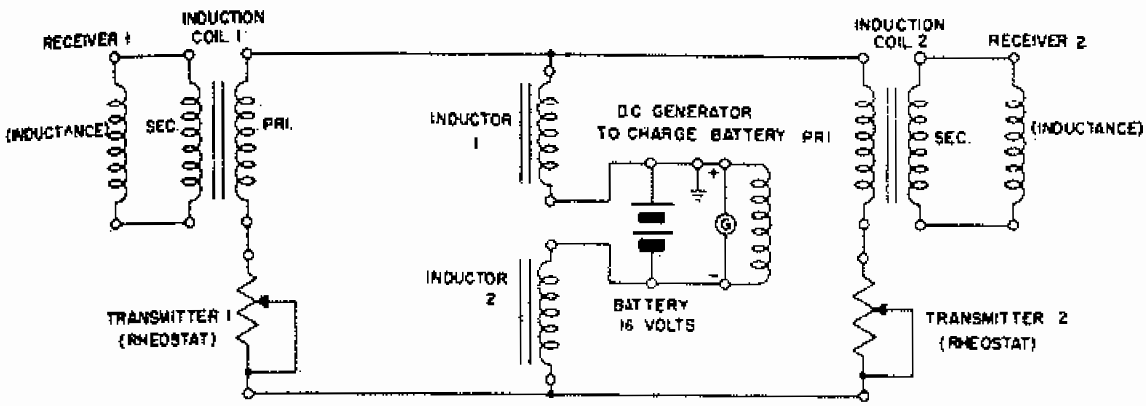


FIG. 19-10

(b) Transformer action takes place from the primary of induction coil 1 to the secondary thereby impressing voltage variations upon receiver 1 which results in sound in the receiver.

(c) Transformer action takes place from the primary of induction coil 2 to the secondary thereby impressing voltage variations upon receiver 2 which results in sound in the receiver.

(d) The voltage variations across transmitter 2 serve no useful purpose.

From the above dynamic analysis it can be seen that if a person talks into transmitter 2 he can be heard in receivers 1 and 2. The instruments in Figure 19-10 are coupled by inductors (Inductor 1 and 2) and the instrument circuits are said to be inductor coupled.

4.05 Another common battery telephone circuit is shown in Figure 19-11 and is normally used in manual and panel type offices. A dynamic circuit of Figure 19-11 is shown in Figure 19-12. A dynamic circuit analysis of Figure 19-12 is as follows:

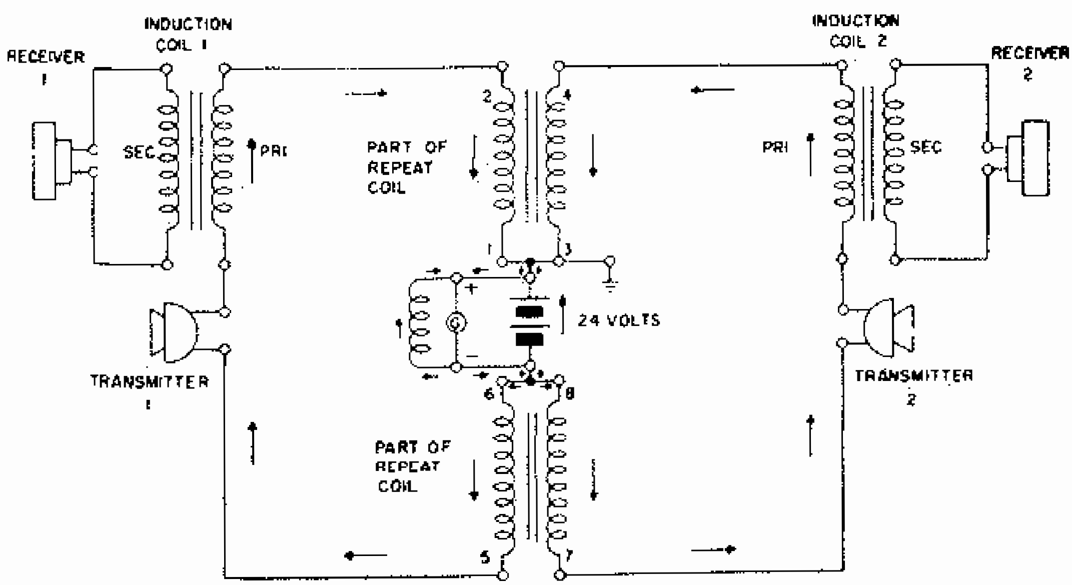


FIG 19-11

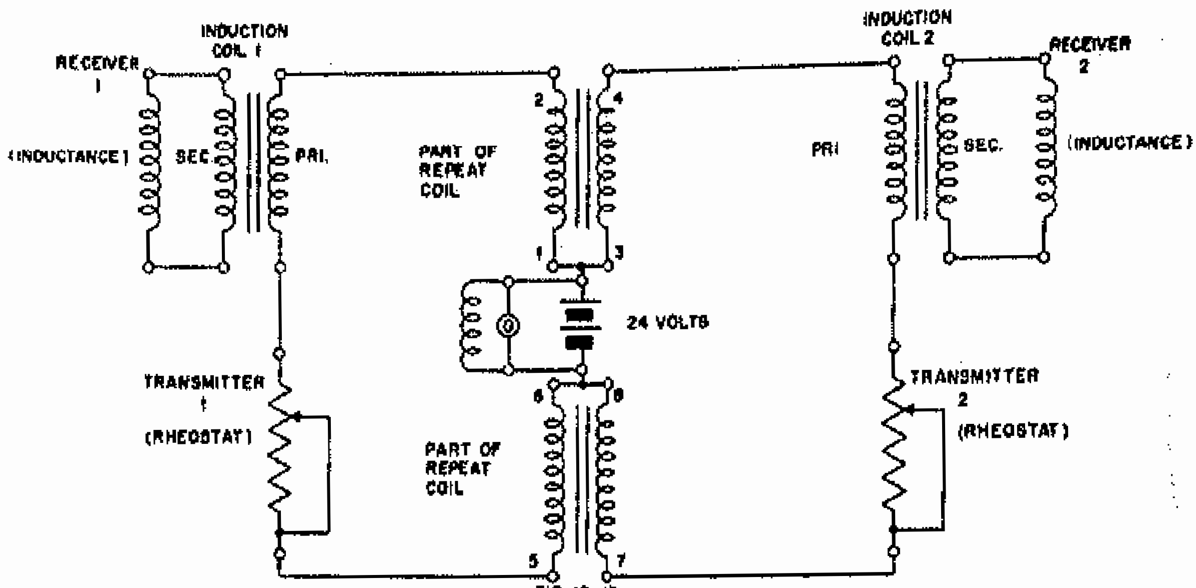


FIG 19-12

(a) When transmitter 1 functions voltage variations are impressed upon the primary winding of induction coil 1 and two windings of the repeat coils in series.

(b) Transformer action takes place from the primary to the secondary of induction coil 1 thereby impressing voltage variations upon receiver 1 and the receiver functions.

(c) Transformer action takes place in the repeat coil and voltage variations are impressed upon transmitter 2 and the primary of induction coil 2.

(d) Transformer action takes place from the primary to the secondary of induction coil 2 thereby impressing voltage variations upon receiver 2 which functions.

(e) The voltage variations upon transmitter 2 serve no useful purpose.

From the above description it can be seen that if a person talks into transmitter 2 he will be heard in receivers 1 and 2. The repeat coil assembly is installed at the central office. The instrument circuits in Figure 19-12 are said to be repeat coil (transformer) coupled.

4.06 The third common battery telephone circuit is shown in Figure 19-13 and is normally used in X-Bar type offices. The dynamic circuit of Figure 19-13 is shown in Figure 19-14. In Figure 19-14 the capacitors allow A.C. or changing D.C. to pass and the inductor block A.C. and changing D.C. The dynamic circuit analysis of Figure 19-14 is as follows:

(a) When transmitter 1 functions voltage variations are impressed upon the primary winding of induction coil 1, the primary winding of induction coil 2 and transmitter 2 in series.

(b) Transformer action takes place from the primary to the secondary of induction coil 1 thereby impressing voltage variations upon receiver 1 and the receiver functions.

5. Principles of Anti-Sidetone

5.01 In order to understand the principles of anti-sidetone it becomes necessary to study a simple sidetone circuit. Sidetone is the transmission and reproductions of sounds through a local path from the transmitter to the receiver of the

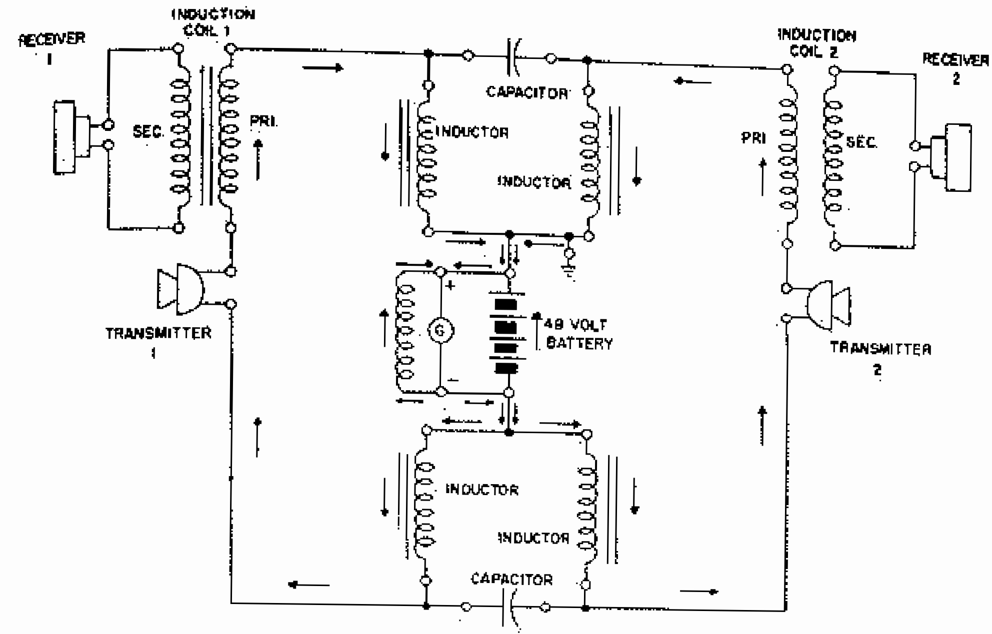


FIG. 19-13

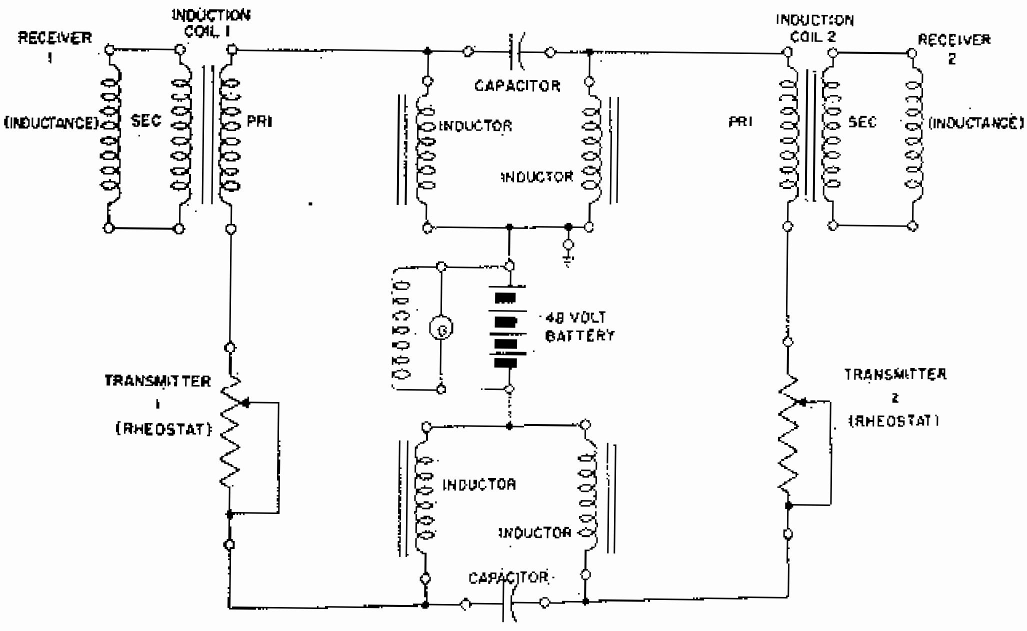


FIG. 19-14

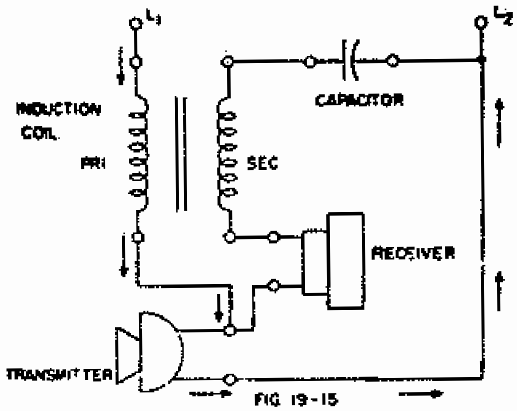


FIG 19-15

same telephone station. Figure 19-15 shows a typical sidetone circuit. The capacitor prevents unchanging D.C. from flowing in the receiver and the secondary winding of the induction coil prevents the transmitter from shunting the receiver and secondary of the induction coil D.C. wise. A dynamic circuit Figure 19-15 is shown in Figure 19-16. A dynamic circuit analysis of Figure 19-16 is as follows for transmitting:

(a) The voltage variations across the transmitter resulting from speech are impressed upon the secondary winding of the induction coil and the receiver in series.

(b) The voltage variations across the receiver result in sidetone.

(c) Transformer action takes place between the secondary and primary of the induction coil with the secondary and primary acting as an auto-transformer, thus the voltage variations are stepped up before being impressed across L1 and L2.

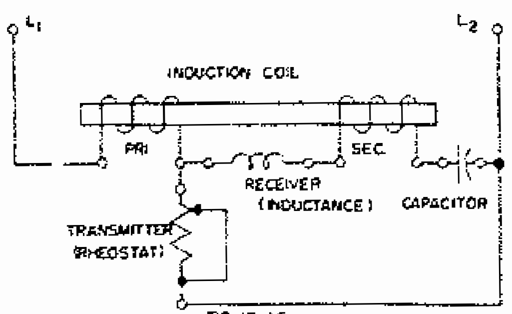


FIG 19-16

A dynamic circuit analysis of Figure 19-16 is as follows for receiving:

(a) When the transmitter at the far end functions voltage variations are impressed across L1 and L2.

(b) The voltage variations across L1 and L2 are impressed upon a series-parallel circuit combination of the primary winding of the induction coil, the receiver, the transmitter and the secondary of the induction coil.

(c) Auto-transformer action takes place from the primary of the induction coil to the secondary and the voltage variations across L1 and L2 are stepped down before being impressed across the receiver and transmitter.

(d) The voltage variations across the receiver cause it to function.

(e) The voltage variations across the transmitter serve no useful purpose.

From the foregoing it can be readily seen that a person speaking into the transmitter results in sidetone, and complete speech transmission. Room noise picked up by the transmitter and reproduced in the receiver through the sidetone path tends to mask the incoming speech and the loudness with which the telephone user talks into the transmitter is influenced to a great extent by the loudness of the sidetone. A reduction in sidetone will result in a receiving improvement because of the reduction in the room noise reproduced in the receiver and a transmitting improvement inasmuch as it influences the telephone user to talk more nearly at a normal volume.

5.02 The "sidetone reduction" circuit illustrated in Figure 19-17 was designed to reduce sidetone. This circuit is merely a modification of the sidetone circuit and it places the receiver and capacitor directly across the secondary winding of the induction coil. This circuit rearrangement results in lowered sidetone but reduces

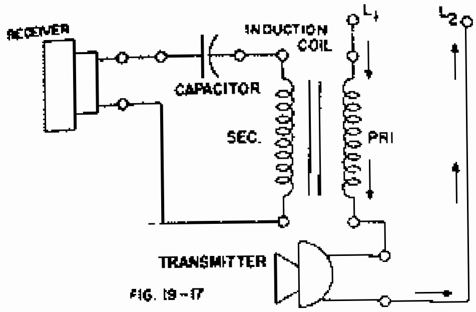


FIG. 19-17

the transmission efficiency of the circuit to a point where it can only be used on short subscriber lines.
The dynamic circuit of Figure 19-17 is shown in Figure 19-18. A dynamic circuit analysis is as follows for transmitting:

(a) The voltage variations across the transmitter are impressed across the line and the primary of the induction coil in series.

(b) No auto-transformer action is present and reduced transmission results.

(c) Transformer action takes place from the primary to the secondary of the induction coil and voltage variations across the receiver result in lowered sidetone.

The sidetone in the receiver is lowered because voltage variations across the primary winding of the induction coil are weaker due to no auto-transformer action. Therefore the voltage variations induced in the secondary of the induction coil result in lower sounds in the receiver.

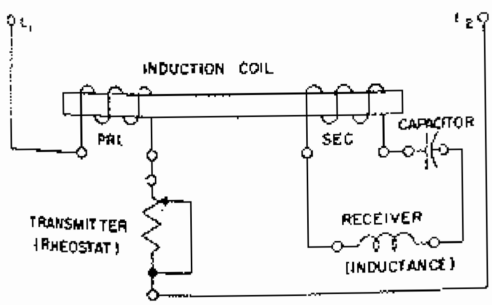


FIG 19-18

The sidetone reduction circuit is a field modification and is being replaced by the anti-sidetone circuit.

5.03 The anti-sidetone circuit was developed to provide improved transmission as well as improved sidetone reduction. Figure 19-19 shows a typical anti-sidetone circuit and it can be seen that the auto-transformer is present as it was in the original sidetone circuit.

The capacitor prevents unchanging D.C. from flowing in the receiver and the secondary and tertiary windings of the induction coil. The capacitor also prevents the transmitter from shunting the receiver, and the secondary and tertiary windings of the induction coil D.C. wise.

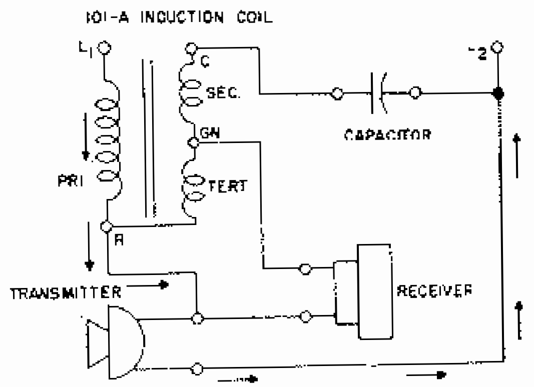


FIG 19-19

Figure 19-20 shows a dynamic circuit of Figure 19-19. A dynamic circuit analysis of Figure 19-20 during transmitting is as follows:

(a) The voltage variations across the transmitter resulting from speech are impressed upon a series - parallel combination of the receiver, tertiary winding of the induction coil and the secondary winding of the induction coil.

(b) The voltage variations across the transmitter are also impressed across the line and the primary wincing of the induction coil in series.

(c) Transformer action takes place between the secondary and primary of the induction coil and they act like an auto-transformer, thus the voltage variations are stepped up before being impressed across the line.

(d) The voltage variations across the tertiary winding of the induction coil are a function of the directly impressed variations from the transmitter as well as the induced variations from the primary and secondary windings of the induction coil.

(e) Due to the design of the tertiary winding of the induction coil the induced voltages and impressed voltages are of the same magnitude but are in opposition to each other and this results in no voltage variation across the receiver as the receiver is in parallel with the tertiary winding.

From the foregoing it can be seen that the magnitude of the impressed and induced voltages across the tertiary winding determine the amount of sidetone reduction.

A dynamic circuit analysis of Figure 19-20 during receiving is as follows:

(a) When the transmitter at the far end functions, voltage variations are impressed across L1 and L2.

(b) These voltage variations are impressed upon a series-parallel combination of the primary tertiary and receiver, secondary and transmitter.

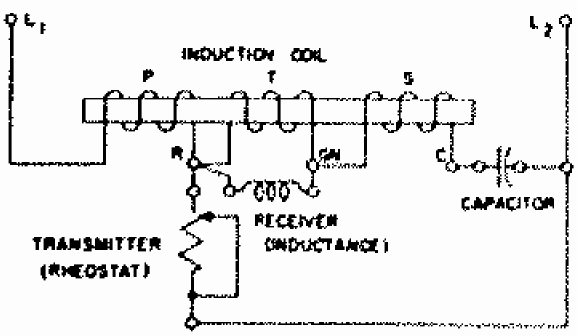


FIG 19-20

(c) The voltage variations across the tertiary winding are a function of the directly impressed voltage variations resulting from the transmitter at the far end as well as the induced voltage variations from the secondary and primary windings.

(d) As in the transmitting condition the induced voltages and impressed voltages in the tertiary winding are in opposition to each other. However, unlike the transmitting condition the voltages are not of the same magnitude and this results in voltage variations across the receiver.

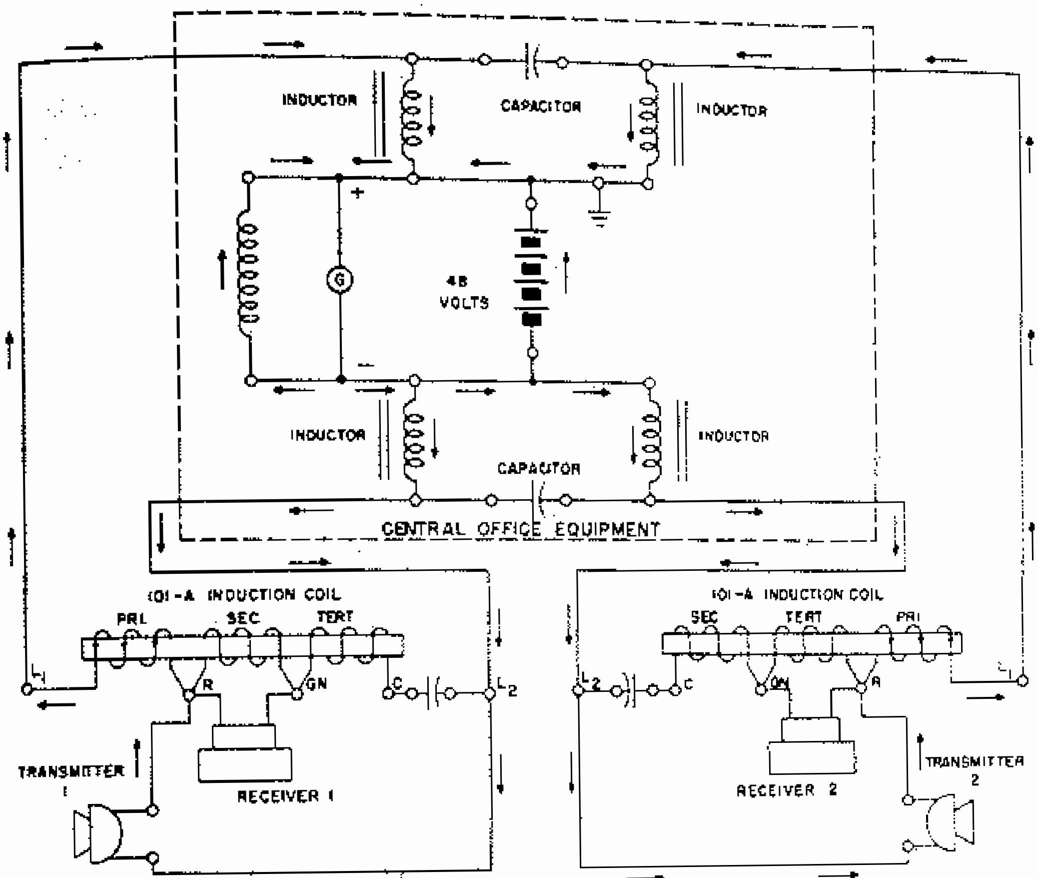
The difference between the receiving and transmitting condition lies in the fact that the impressed and induced voltages across the tertiary winding cancel in the transmitting case and do not cancel in the receiving case. In the transmitting case the induced voltage from the secondary to the tertiary, which is a function of the impressed voltage across the secondary is very strong due to the fact that the transmitter which is generating the impressed voltage variations is directly connected to the secondary winding. However, in the receiving case the impressed voltage across the secondary winding is weak. This is because the transmitter which is generating the impressed voltage variations is at the far end of the circuit and is actually separated from the secondary winding by the resistance of the line.

5.04 Figure 19-21 shows a drawing of two anti-sidetone instruments connected through a capacitor central office circuit. Figure 19-22 shows a dynamic version of Figure 19-21.

6. Questions

1. What is a series telephone circuit?

2. Of what use is a D.C. equivalent circuit? Varying D.C. or A.C. circuit?



ANTI-SIDETONE INSTRUMENT 1 ANTI-SIDETONE INSTRUMENT 2

FIG 19-21

3. How is a battery represented in a dynamic circuit? Why?

4. Can the transmitter be considered a pulsating D.C. generator? Why?

5. What is a local battery telephone circuit?

6. What is a common battery telephone circuit?

7. Give three methods of coupling used in a common battery telephone system.

8. How is an inductance represented in a dynamic circuit? Why?

9. What is sidetone?

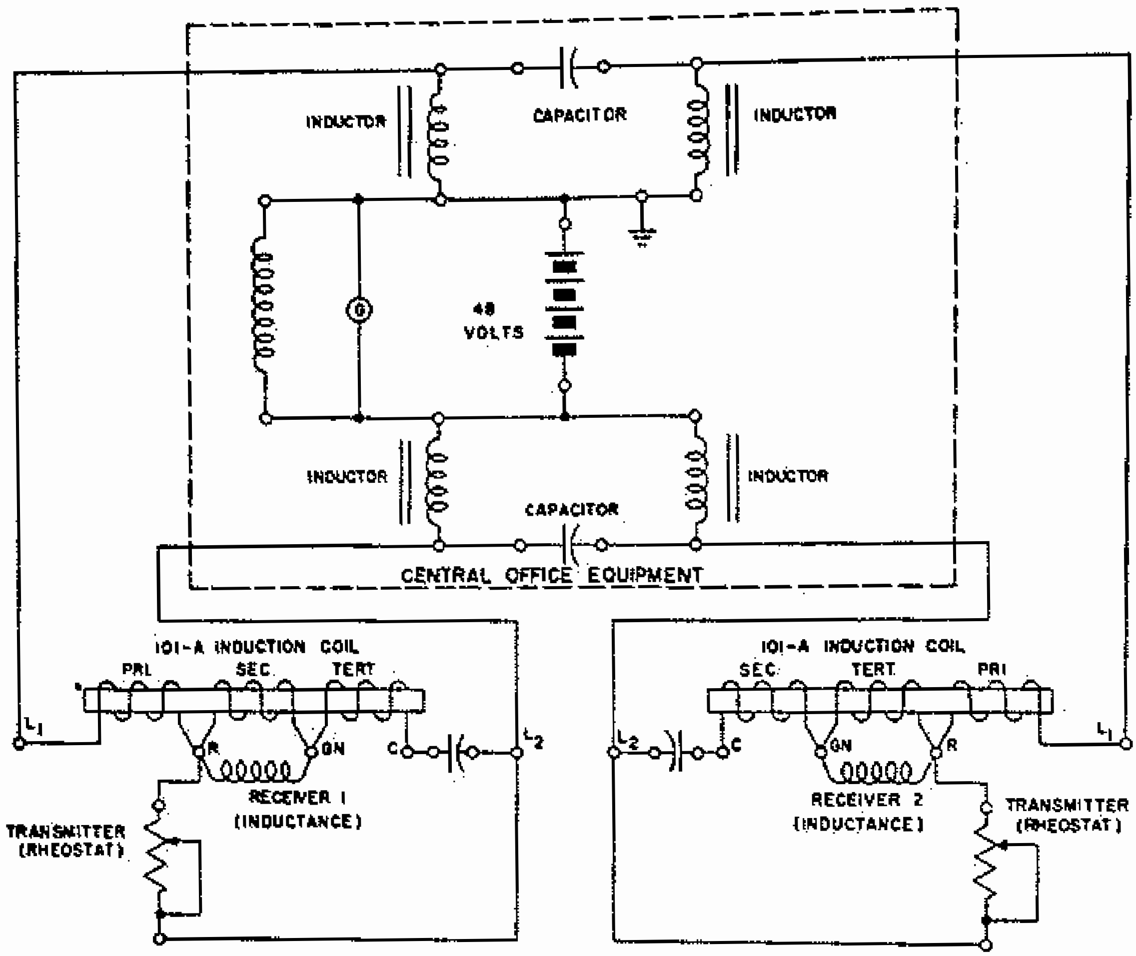
10. What is the disadvantage of a sidetone reduction circuit?

11. Why was the anti-sidetone circuit developed?

12. What are the advantages of the anti-sidetone circuit?

13. Why is sidetone reduced in an anti-sidetone circuit?

14. What would be the result if the tertiary winding of an anti-sidetone instrument were open? If the secondary winding were short circuited?



INDUCTOR
CAPACITOR
INDUCTOR
48
VOLTS
INDUCTOR
CAPACITOR
INDUCTOR
CENTRAL OFFICE EQUIPMENT
101-A INDUCTION COIL
PRI.
SEC.
TERT.
R
GN
C
RECEIVER 1
(INDUCTANCE)
TRANSMITTER
(RHEOSTAT)
101-A INDUCTION COIL
SEC.
TERT.
PRI
GN
R
C
RECEIVER 2
(INDUCTANCE)
TRANSMITTER
(RHEOSTAT)

FIG. 19-22

CHAPTER XX

VARISTORS

1. General

1.01 Varistors are VARiable resISTORS and derive their name from the first three letters of the word variable and the last six letters of the word resistors.

Varistors are classed as "metallic rectifiers" or as "crystal rectifiers" such as the copper-oxide, selenium, or germanium crystal rectifiers.

All classes of varistors are in general made of semi-conductors, that is, materials whose conductivity lies between that of conductors and insulators.

2. Copper-Oxide Rectifier

2.01 The copper-oxide rectifier is a sandwich consisting of a layer of cuprous oxide on copper.

These cells are produced by heating a copper disc. in a furnace to a temperature of about 1,000 degrees F and then quenching it in water.

This treatment produces a thin film of cuprous oxide with an outer layer of cupric oxide.

The cupric oxide is removed leaving a thin layer of cuprous oxide on one side.

Contact with the copper-oxide surface can be made by holding a lead disc against the oxide surface under pressure or by electroplating a nickel coating on the surface of the oxide.

These discs are shapped like washers and are assembled alternately with lead washers on a bolt so they can be clamped tightly together (with a pressure of 500 to 2000 pounds per square inch) to secure good electrical contact.

The lead nickel or other conducting material applied to the outer surface of the oxide is known as the "outer contact".

When a potential is applied between the copper and the outer contact, it is found that the current is not proportional to the applied voltage and that it depends on the direction of the applied potential.

Such a combination offers a low resistance path to current flowing from the copper to the copper-oxide but a high resistance path to the current flowing from the copper oxide to the copper.

2.02 A complete assembly is known as a "varistor" and the number of discs necessary in each assembly (or stacks) is determined by the voltage of the current to be rectified and the number of stacks which must be connected in parallel is determined by the amperage output desired.

Broadly, one disc is required for each 3 volts of rectified output and 1½ inch disc will carry .2 to .4 amperes depending on whether fins are placed between the discs to dissipate the heat generated by their operation.

The direction of greatest current can be remembered if a person recalls that copper has a great number of free electrons and if a negative potential is applied to the copper more current will flow.

If a negative potential is applied to the "outer contact" and the oxide, there being few free electrons in a semi-conductor, there will be comparatively little current flowing.

2.03 Figure 20-1 shows the symbol for a copper-oxide varistor.

The symbol for the varistor was made when current flow was assumed to be from positive to negative and the arrow was assumed to point in the direction of the greatest current flow.

Since we are now assuming current flow is from negative to positive the greatest current flow will be against the symbol arrow.

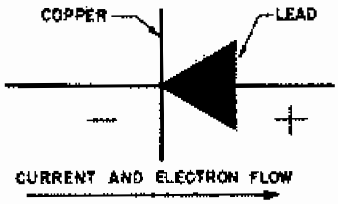


FIG. 20 - 1

2.04 Figure 20-2 shows the construction of a copper-oxide varistor.

2.05 When 0.2 volts is applied in the conducting direction of a copper-oxide varistor disc 3/4 of an inch in diameter a current of approximately 0.003 amperes will flow.

If the potential is increased to 0.3 volts the current flow will increase to about 0.020 amperes.

The copper-oxide varistor has a current carrying capacity of approximately 0.2 amperes per square inch and with special cooling this value may be doubled or tripled.

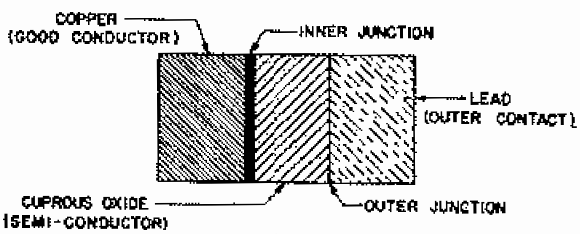


FIG. 20 - 2

3. Theory of Operation of Copper-Oxide Varistors

3.01 In passing from the copper to the outer contact, the current must cross the inner junction between the copper and the oxide, and the outer junction.

Experiments have shown that the conductivity in the body of the oxide and the outer contact obeys ohm's law and that the non-linearity in the current voltage relation is due to the peculiar nature of the conduction at the inner junction.

The phenomenon of non-linear voltage-current relations in some substances at the junction of dissimilar substances has been known for a long time.

Early in this century many materials were employed in "wireless" reception which exhibited highly polarized non-linear characteristics.

These materials consisted of a lump of some mineral such as galena, silicon, iron or copper pyrites, zincite, borite or silicon-carbide.

In the process of signal detection these materials made up one side of a circuit while a feeler wire called a "catswisker" bearing on the material was connected to the other terminal.

The free electrons moved from the crystal to the metal point bearing upon them.

The more stable operation of the vacuum tube detector replaced the crystal detector.

4. Application of Copper-Oxide Rectifier

4.01 The rectifying unit consists of four arms, each arm containing a stack of copper-oxide discs or two or more in parallel if the output is greater than one stack will supply.

During half of the A.C. cycle current will flow from the secondary of the transformer (Figure 20-3) to terminal 2, through the rectifying arm to 3 through the D.C. output load (or battery) to 1, through the rectifying arm to 4 and back to the other end of the secondary.

During the other half of the A.C. cycle current flows from the secondary to 4, through the rectifying arm to 3, through the D.C. output load to 1, through the rectifying arm to 2 and back to the secondary.

It will be noted that the rectified current during each half cycle always flows from 3 to 1 in the same direction.

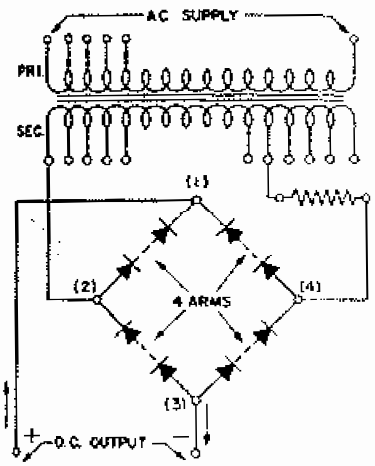


FIG 20-3

4.02 Copper-oxide rectifiers are used for charging small P.B.X. and Central office storage batteries, charging emergency cells, filament or plate supply in small repeater installations and other applications where a small output is required.

4.03 The circuits shown in Figure 20-4 and Figure 20-5 are just alike except that a copper oxide VARISTOR is bridged across the receiver in Figure 20-5. The voltages produced in the receiver due to the operation of the transmitter are too low to cause appreciable current to flow through the varistor. Thus, the presence of the varistor in the circuit does not appreciably affect transmission. However, if a higher voltage is connected to the terminals of a varistor, it acts as a good conductor.

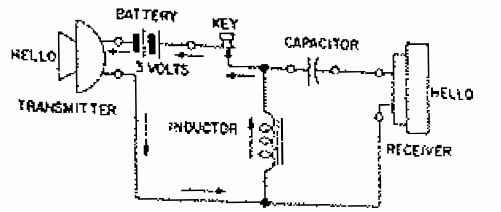


FIG 20-4

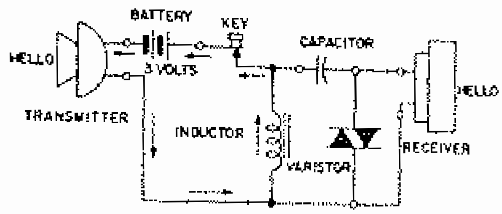


FIG 20-5

4.04 When the battery supply to the inductor in Figure 20-6 is opened, the coil discharges as indicated, producing a loud click in the receiver. However, when the battery supply in Figure 20-7 is opened, a good part of the discharge from the coil goes through the varistor so that practically no click is heard in the receiver. When the coil and capacitors have reversed the current flow the current will then flow through the other half of the varistor.

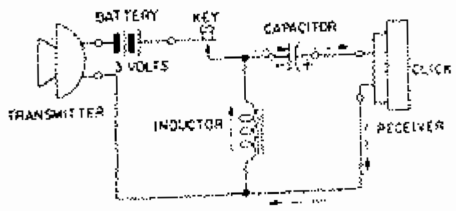


FIG 20-6

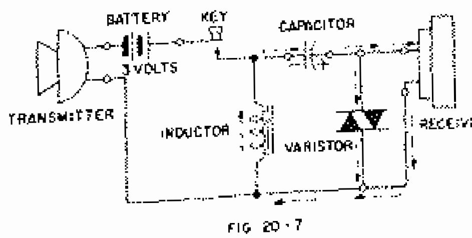


FIG 20-7

5. Sizes and Types of Copper-Oxide Rectifiers

5.01 There are many sizes and types of copper-oxide rectifiers to meet the various purposes for which they are suited.

Most of these are of the full wave type and are provided with secondary taps and a means of switching to them, to control the output.

Where it is necessary to filter the ripples or noise a small choke coil is connected in the output circuit.

The smaller sizes of rectifiers are enclosed in rectangular metal cases suitable for shelf mounting.

The larger sizes are enclosed in a metal case suitable for mounting on frameworks.

Most types have an output of 1 ampere and a few have outputs between 1 and 3 amperes.
One type used for trickle charging emergency cells in large power plants has an output of 6 amperes at 10 volts.

6. Aging of Copper-Oxide Rectifiers

6.01 A copper-oxide varistor changes its resistance to current flow with changes in surrounding (ambient) temperature and age.

Aging, however, causes the varistor to increase its resistance in the conducting direction and decreases it in the non-conducting direction.

The aging effect occurs regardless of whether or not the varistor is in operation but is accelerated if it is operated in a high surrounding temperature.

7. Selenium Rectifier

7.01 The selenium rectifier consists of disks of nickel-plated steel or aluminum that have a thin coating of selenium on one side.

When the selenium is first applied it has a black polished surface but this is changed to the gray crystaline form by a series of heat treatments.

This selenium surface is then sprayed with an alloy to form the inner junction and it is between this electrode and the selenium where the barrier layer is formed.

The sprayed alloy is the good conductor and the selenium the semi-conductor and the free electrons pass through the barrier readily in the direction from the alloy to the selenium.

7.02 Figure 20-8 shows the symbol for a selenium varistor.

7.03 Figure 20-9 shows the construction of a selenium varistor.

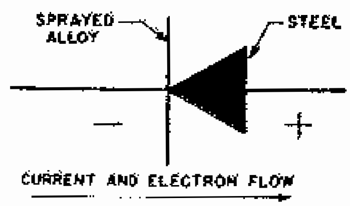


FIG. 20 - 8

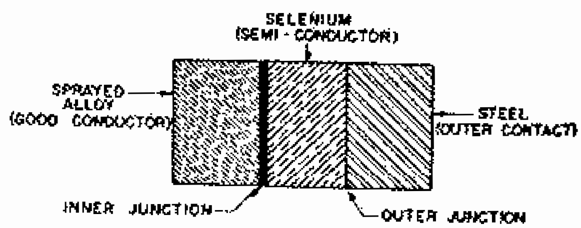


FIG. 20 - 9

The selenium-coated washers are assembled in stacks in much the same way as copper-oxide washers and the hook ups in which they are used in circuits are the same.

Since the rectifying action is wholly in the selenium coated washer itself and does not require a washer of lead to complete the contact to the washer surface it is not necessary to employ such heavy pressures in the stack assemblies as in the copper-oxide stacks.
Expansion and contraction of the assembly and mounting stud therefore do not change the electrical contact.

Higher plate temperatures are permissable with the selenium rectifier.

Individual selenium disks operate at about three times the voltage of a copper-oxide disc.

The selenium rectifier results in a smaller lighter and more efficient rectifier than the copper-oxide.

8. Germanium Rectifier

8.01 The germanium varistor is a crystal rectifier, or crystal diode, it has a cartridge type construction and the appearance of a one-watt fixed resistor.

A tungsten feeler or catswisker bears upon a thin disc of optically polished germanium soldered to the end of a wire.

The germanium disc is prepared from pure germanium powder mixed with a small amount of tin.

The powder is melted and when it has cooled a crystallized ingot results which is cut into wafers 0.6 millimeters thick and 3 millimeters square.

The polished discs form a lattice imperfection semi-conductor.

When the tungsten terminal is made positive, free electrons move in the forward direction from the semi-conductor into the tungsten, but when the polarity is reversed, very few free electrons are able to cross the boundary into the semi-conductor.

In the copper-oxide varistor, we had the free electrons move more freely from the metal (copper) into the semi-conductor (cuprous oxide) when the metal is negative.

In the germanium crystal varistor we find the free electrons moving more freely when the semi-conductor (germanium crystal) is negative.

This phenomenon is not readily explainable.

The crystal rectifier is small in size and light in weight.

8.02 Figure 20-10 shows the symbol for a germanium varistor.

8.03 Figure 20-11 shows the construction of a germanium varistor.

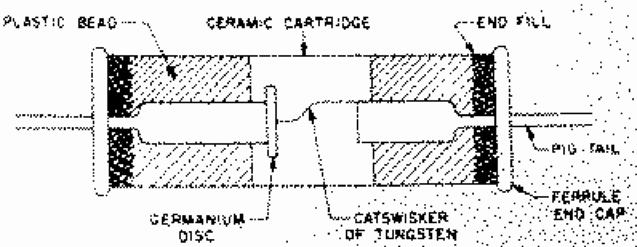


FIG. 20 - 11

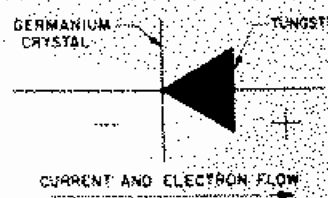


FIG 20-10

9. Silicon Carbide or "Thyrite" Varistor

9.01 In this type of varistor the current increases much more rapidly than proportional to the voltage, but it is the same for two directions of the applied potential.

It consists of a large number of granules of silicon carbide bonded together by a ceramic.

Each silicon-carbide granule touches its neighbors in only a few small contact areas.

The electrical characteristics are determined largely by the number of these contacts.

While any one contact may rectify to some extent, the overall characteristic shows practically no rectification because there are numerous contacts in series and in parallel.

9.02 In comparing the characteristics of varistors made with silicon-carbide and with copper-oxide respectively:
The current through the silicon-carbide varistors does not depend on the direction in which the voltage is applied. The ratio of the resistance at high and low voltages is between 100,000 and a 1,000,000 which is about 100 times as great as for the standard copper-oxide varistor.

The current through the silicon-carbide varistor never varies as rapidly with voltage as it does for most copper-oxide varistors. The copper-oxide and silicon-carbide types supplement each other; the copper-oxide type is used essentially as a low voltage varistor while the silicon-carbide is a high voltage varistor.

9.03 Figure 20-12 shows the symbol for a silicon-carbide varistor.

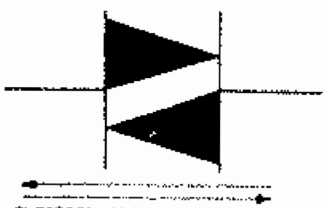


FIG 20-12

10. <u>Questions</u>

1. What is a varistor?
2. In general, what are varistors made from?
3. In a copper-oxide varistor is the current proportional to the voltage?
4. Does the current in a copper-oxide rectifier depend on the direction of the applied potential?
5. If the current through copper-oxide rectifier is small, what direction is the current flowing? If the current is large what direction is the current flowing?
6. What is the symbol for a copper-oxide varistor?
7. Will the greatest current flow be against the arrow of the symbol for a copper-oxide varistor?
8. What are copper-oxide rectifiers used for?
9. What trouble would a short circuited varistor in Figure 5 cause?
10. What are the advantages of a selenium rectifier over a copper-oxide rectifier?
11. How is a germanium varistor made?
12. In which direction will the greatest current flow in a germanium varistor?
13. What is the symbol for the silicon-carbide varistor?
14. Does the current through the silicon-carbide varistor depend on the direction in which the voltage is applied?

CHAPTER XXI

THERMISTORS

1. General

1.01 Thermistor is a contraction of the expression "Thermally sensitive resistor". Thermistors are made in a variety of forms from mixtures of certain metallic oxides pressed into disks, extruded into rods or formed into beads. In all forms they are hard and durable. Suitable electrical contacts are attached to these forms. Thermistors are produced with resistance values ranging from a few ohms to several megohms. They can be made for use wherever temperature variations exist or can be produced. The variations in temperature may result in three ways: Externally by the change in ambient temperature. Directly as when current is passed through the thermistor, thereby heating it. Indirectly, as when current controlled as desired is passed through a small heater associated closely with the thermistor.

2. Directly Heated Thermistor

2.01 The 1A thermistor is of the directly heated type. It consists of a small bead of sintered uranium oxide in an evacuated nitrogen filled glass envelop enclosed in a fibre tube with metal end caps which act as terminals. Figure 21-1 is the symbol for a drectly heated thermistor.

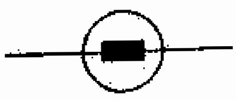


FIG. 21-1

If sufficient current is passed through a 1A thermistor to result in the dissipation of 15 milliwatts at 75°F. its 60,000 ohms resistance decreases about 40,000 ohms to a new value of 20,000 ohms. This is a ratio of 3 to 1. When 75 milliwatts is applied the resistance decreases about 59,400 ohms to a new value of 600 ohms. This is a ratio of 100 to 1. Since the thermistor can not be heated or cooled instantly the resistance of the thermistor will not change instantly in response to a change of power applied to it. This effect can be utilized and controlled for time delay applications.

3. Indirectly Heated Thermistor

3.01 The 2A thermistor is an indirectly heated thermistor. It consists of a heater and a thermistor. It is most useful where electrical separation of controlling and controlled circuit is needed. The heater is also useful in thermostating the thermistor so that the thermistor can be used as a directly heated device, without undesirable effects due to ambient temperature changes. Figure 21-2 is the symbol for an indirectly heated thermistor.

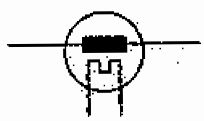


FIG. 21-2

The heater has 100 ohms resistance and the maximum continuous current is 25 milliamperes either A.C. or D.C. The thermistor has 2,800 ohms when no current is flowing at 77°F. When about 2 milliamperes flows through the heater the resistance of the thermistor drops to a value of about 2,200 ohms. The following data shows the heater current and thermistor resistance for a 2A thermistor.

6 milliamperes	1000 ohms
8 milliamperes	400 ohms
10 milliamperes	200 ohms
12 milliamperes	100 ohms
14 milliamperes	70 ohms
16 milliamperes	40 ohms
18 milliamperes	25 ohms
20 milliamperes	18 ohms

4. Summary

(a) Ohm's law is obeyed if the temperature of the element is held constant.

(b) The unique properties of a thermistor are due basically to the high negative temperature coefficient of resistance.

(c) No rectification occurs in thermistors.

(d) Resistance changes do not instantaneously follow changes of applied power but depend on the resulting temperature change.

(e) When the power is suddenly increased from one value to a higher value, the resistance begins to decrease rapidly at first and then more and more slowly until it approaches its new steady value.

(f) At low currents the voltage across the thermistor is proportional to the current, at somewhat higher currents the voltage does not increase as rapidly as the current.

5. Questions

1. How are thermistors made?
2. The variations in temperature may result in three ways. Name them.
3. What is the symbol for a directly heated thermistor?
4. What is the symbol for an indirectly heated thermistor?
5. What are thermistors used for?
6. What resistance will a 1A thermistor have if 15 milliwatts of power is dissipated by the thermistor at 75°F?
7. What does a 2A thermistor consist of?
8. What is the resistance of the heater of a 2A thermistor?
9. What is the resistance of the thermistor at 77°F with no current flowing through it?
10. If 20 milliamperes flow through the heater what will the thermistors resistance be?
11. When power is suddenly increased from one value to a higher value what happens to the resistance of a thermistor?

CHAPTER XXII

FILTERING

1. Introduction

1.01 In telephone transmitting and receiving circuits a constant D.C. supply is necessary and a battery may be used.

1.02 Another method of obtaining a constant D.C. supply is by the use of a D.C. generator and a filter. The output of a D.C. generator is pulsating D.C. See Figure 22-1. A filter is used to smooth out the pulsations or ripples so as to give as nearly a constant D.C. as possible.

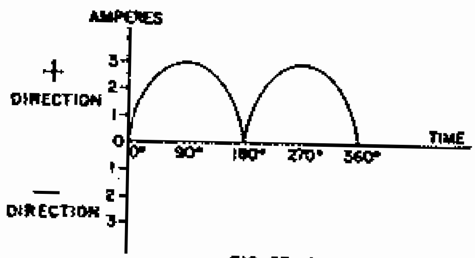


FIG. 22-1

2. Capacitance Filter

2.01 Figure 22-2 illustrates a typical capacitance filter. In Figure 22-2 the capacitor stores energy while the output of the generator is rising and returns energy to the circuit while the generator output is decreasing. The effect of the capacitor on the pulsating D.C. output is illustrated in Figure 22-3. The shaded area illustrates the filtering action of the capacitor which results in a more nearly constant D.C. The effectiveness of this filter depends upon the value of the capacitor and the size of the load.

This type of filter is used where the D.C. supply does not have to be too well filtered and where the load is not too great.

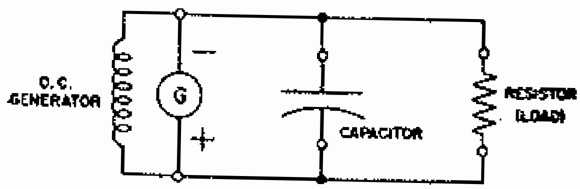


FIG. 22-2

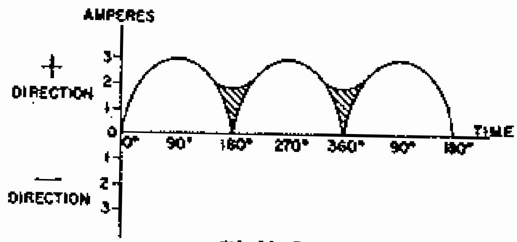


FIG. 22-3

3. Inductance Filter

3.01 Figure 22-4 illustrates a typical inductance filter. In Figure 22-4 the inductor stores energy in its magnetic field while the generator output is rising and returns energy to the circuit while the generator output is decreasing. The effect of the inductor on the pulsating D.C. output is similar to that of the capacitor shown in Figure 22-3. The effectiveness of this filter depends upon the load and value of the inductance.

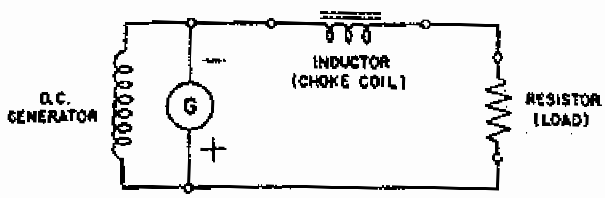


FIG. 22-4

4. Capacitance and Inductance Filter

4.01 In actual practice most filters consist of a combination of capacitance and inductance. Figure 22-5 illustrates a typical inductance-capacitance filter which combines the effects both components. The functions of the components in this filter circuit is basically to deliver energy when the circuit needs it and with two components this effect is additive.

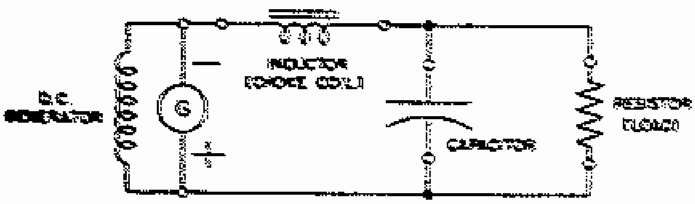


FIG. 22-5

If even more filtering is necessary more sections of inductance and capacitance may be added as in Figure 22-6.

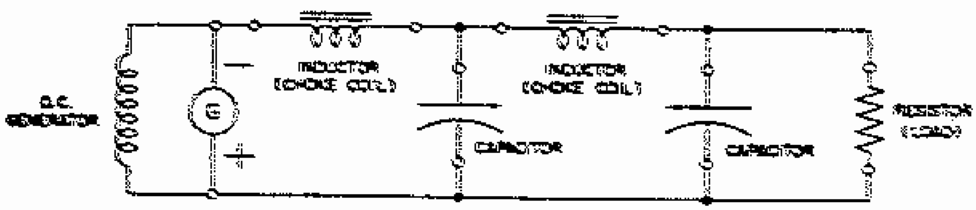


FIG 22-6

5. Applications

5.01 The direct current required in a central office falls into two classes, "signaling" current, which is used to operate all the various types of electro-mechanical apparatus such as relays, etc., and "talking" current which supplies the medium for voice transmission. Since practically all equipment for generating direct current, such as motor-generators and rectifiers, introduces ripples or noise in their output it is necessary that filters be employed to keep "talking" circuits free from such distrubances.

Filters comprise a combination of inductance and capacitance which may range in size and type from a small coil and capacitor to care for the output of a small rectifier, up to a large coil weighing one or two tons associated with a group of condensers to filter the talking current for a large central office.

5.02 In telephone plant applications the D.C. generator is connected as shown in Figure 22-7. Due to the low internal resistance of the battery the D.C. pulsations are by-passed which provides more filtering.

6. Questions

1. Why does "talking" battery have to be filtered?

2. Briefly, how does a filter work?

3. What three components can be used as filters?

4. What limits the effectiveness of a capacitor when used as a filter?

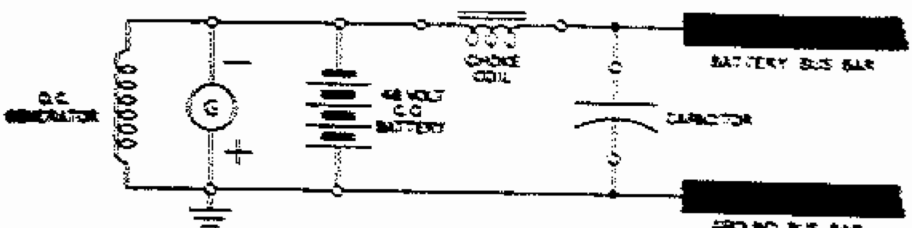


FIG 22-7

CHAPTER XXIII

SUPERIMPOSED CURRENTS

1. Types of Currents

1.01 Figure 23-1A represents graphically the current flow in Figure 23-1B. In Figure 23-2B

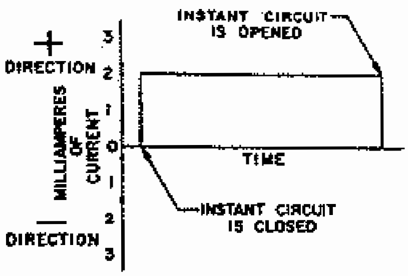


FIG. 23 - 1A

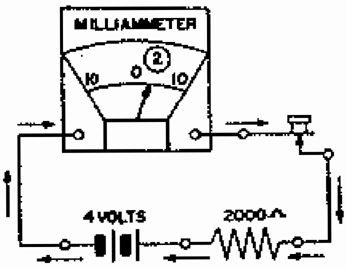


FIG. 23 - 1B

battery has been reversed so that the current flows the other way. In both cases, the current is spoken of simply as DIRECT CURRENT. Figure 23-2A - the direction of the current is represented by its position below the zero line and the current is said to be flowing in the negative direction. The current in Figure 23-1A is flowing in the positive direction.

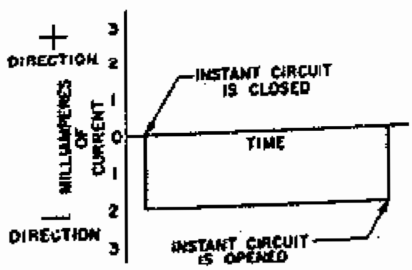


FIG. 23 - 2A

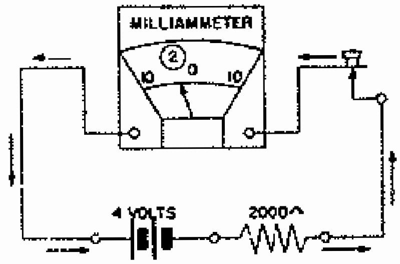


FIG. 23 - 2B

1.02 The current represented in Figure 23-3A is being varied, due to the steady operation of the transmitter, and is known as FLUCTUATING DIRECT CURRENT. If the battery polarity was reversed, in Figure 23-3B the fluctuations would be illustrated below the zero line in Figure 23-3A due to the reversal in current flow.

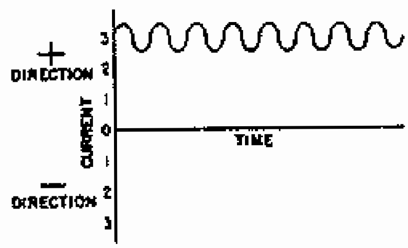


FIG. 23 - 3A

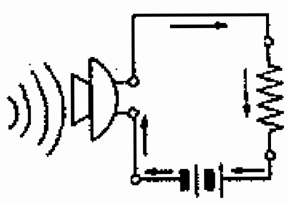


FIG. 23 - 3B

1.03 The current in a circuit which is opened and closed periodically is represented in Figure 23-4A. We speak of this as INTERRUPTED DIRECT CURRENT or DIRECT-PULSATING CURRENT.

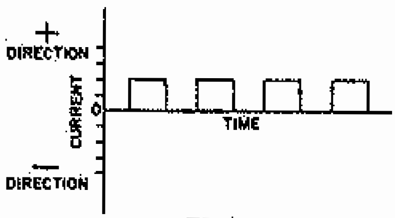


FIG. 23 - 4A

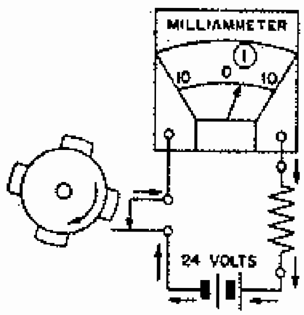


FIG. 23 - 4B

1.04 Figure 23-5A represents the alternating current produced in the secondary circuit of Figure 23-5B when the transmitter diaphragm is vibrating steadily.

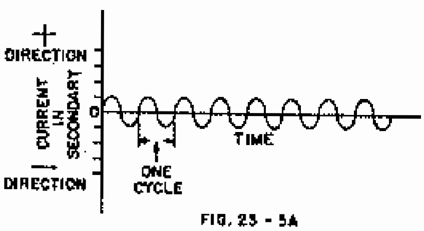


FIG. 23 - 5A

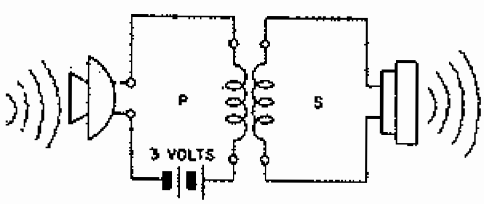


FIG. 23 - 5B

1.05 A battery has been included in the secondary circuit of Figure 3-6. When the transmitter diaphragm is vibrating there are two E.M.F.'s tending to cause current to flow in the secondary circuit.

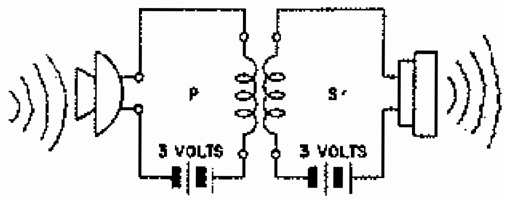


FIG. 23 - 6

Figure 23-7A illustrates the battery current. Figure 23-7B illustrates the transmitter induced current and Figure 23-7C illustrates the sum of these two currents. It is the sum of these two currents which results in the total current in the secondary circuit and is known as the Effective Current. Figure 23-8 represents the current which flows in this circuit. Current produced in this manner is referred to as SUPERIMPOSED CURRENT.

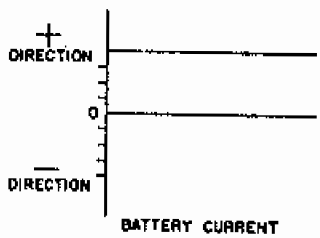


FIG. 23 - 7A

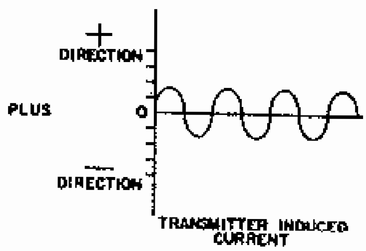


FIG. 23 - 7B

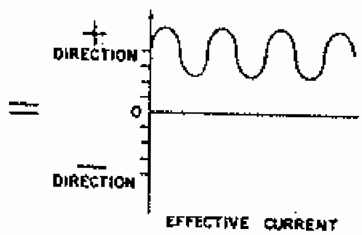


FIG. 23 - 7C

It may also be referred to as fluctuating direct current. Superimposed current is a combination of A.C. and D.C. in which the amounts and polarity of either the A.C. or D.C. determine the characteristic of the graph representing them.

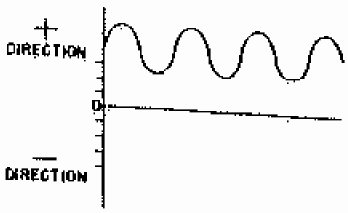


FIG 23 - 8

1.06 Figure 23-9 illustrates basically a typical superimposed current circuit of the type used in the telephone plant. It can be seen that either negative or positive battery may be combined with the A.C. from the generator by operating the proper key.

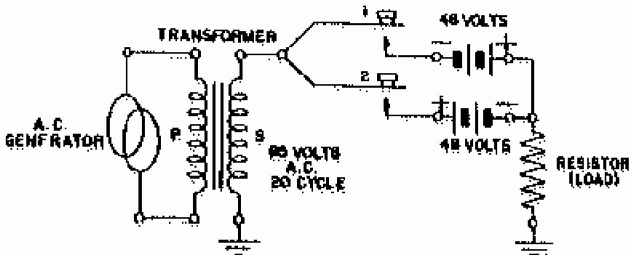


FIG. 23 - 9

Figure 23-10 illustrates graphically the current which will be produced when Key #1 is operated and is referred to as "superimposed positive current".

FIG 23 - 10

In the graph of Figure 23-10 the amounts of A.C. and D.C. combined are of different values than those of Figure 23-6. These values are approximately the ones used in the telephone plant and are determined by the functions they must perform.

Figure 23-11 illustrates graphically the current which will be produced when Key #2 is operated and is referred to as "superimposed negative current".

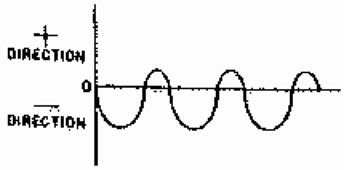


FIG 23 - 11

2. Reasons for Superimposing Currents

2.01 Superimposed currents are used in the telephone plant for party line selective ringing which is described in Chapter XXV. It may be said that superimposed ringing current is used to perform two functions over one circuit. Superimposed current is used to select the correct subscriber on a party line circuit and then ring the bells. (Chapter XXV) In circuits where party selection is not accomplished by superimposed ringing or in a single line, the superimposed current is used to ring the bell and operate a D.C. "tripping relay" in the central office. In most cases the A.C. component is separated from the D.C. at the subscriber set by the use of a capacitor. (Chapter XXV, PARAGRAPH 6)

3. Questions

1. How is the direction of current flow in a circuit graphically illustrated?

2. Make a graph illustrating A.C. current flow.

3. Make a graph illustrating a combination of A.C. and D.C. current.

4. What is the name given to this current flow?

5. Will positive superimposed current graphically appear above or below the zero line?

6. What two things is superimposed current used for?

CHAPTER XXIV

THREE ELEMENT COLD CATHODE TUBES

1. General

1.01 A gas filled cold cathode tube consists of three electrodes in an atmosphere of gas in an envelope. By virtue of the non-conducting and conducting properties of the gas, the tube may be used for as follows:

A voltage regulator
A relay
A rectifier

For certain purposes cold cathode tubes possess advantages over vacuum tubes as follows:

No filament current required.
No current drain until they start to perform their functions.

Typical gas filled cold cathode tubes are as follows:

313
333
346
353

These tubes are being used more and more extensively in the telephone plant and the most important application to date is in the four party ringing circuit where the tube takes the place of a relay and capacitor. The tubes listed operate on the same principles. They are similar in general construction of their bulbs and electrodes and differ mainly in their bases and terminals. They differ slightly in their operating voltages. The glass bulb of each is coated with special black paint to prevent light getting in the tube which would effect its operation. Figure 24-1 shows the symbol for a cold cathode tube. The black dot in the symbol indicates that the envelope contains gas.

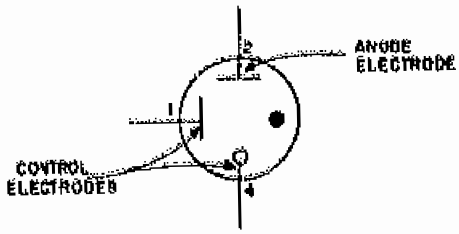


FIG. 24-1

2. Theory

2.01 Cold cathode gas filled tubes depend for their operation on the conducting and non-conducting properties of a gas. Under ordinary conditions gases are non-conducting but, when ionized they may become conducting and remain so as long as sufficient voltage is applied.

If one or more electrons have been removed from an atom of gas as may happen if the atom has been hit by a rapidly moving electron or atom, the remaining part of the atom will be positive charged and is called a positive ion. Should an electron attach itself to a neutral atom, the atom will be negative charged and is called a negative ion. The process in which ions are formed is called ionization. Ordinarily in gas there are a few ions present and if a voltage is applied between two electrodes in the gas there will be a minute current flow resulting from the charges carried by the drift of free electrons or of negative ions toward the positive electrode, and the drift of the positive ions toward the negative electrode. This current flow is extremely small and is not observable with ordinary instruments.

If the potential difference is low the velocities of the ions and electrons are low and considerable recombinations of electrons and ions take place so that only a fraction of the ions produced reach the electrodes and the current is small. Increasing the applied potential increases the velocities of the electrons and at a certain potential difference, which depends upon the composition of the gas, the velocities of the electrons may be sufficient to cause electrons to be completely detached from the atoms in their collisions. These atoms become positive ions and move toward the negative electrode (cathode). Should they strike it hard enough to knock off a sufficient number of electrons ionization will proceed rapidly causing a pronounced increase in current flow. The voltage at which this condition occurs is called the "breakdown voltage" and it varies from 65 to 85 volts, depending on the individual tube.

Under certain suitable conditions of gas pressure and voltage difference between the electrodes, a large current may flow between the electrodes this current being carried principally by the large number of electrons liberated by the bombardment of the negative electrode. With conduction occurring, the voltage between the electrodes may be decreased appreciably below the breakdown voltage before conduction stops. The lowest voltage at which conduction continues is called the "sustaining voltage" and varies from 60 to 75 volts. After conduction has stopped it is necessary to raise the voltage to the breakdown voltage in order to start it again.

The foregoing description explains why at low voltage, gas tubes are non-conducting and become conducting on the application of a sufficient high voltage.

3. Description of Operation

3.01 The elements of a 333 type tube are shown in Figure 24-2. The semi-circular electrodes are coated with an activated surface of barium oxide to facilitate the release or emission of electrons. The central electrode which projects through a glass sleeve is the anode. The bulb

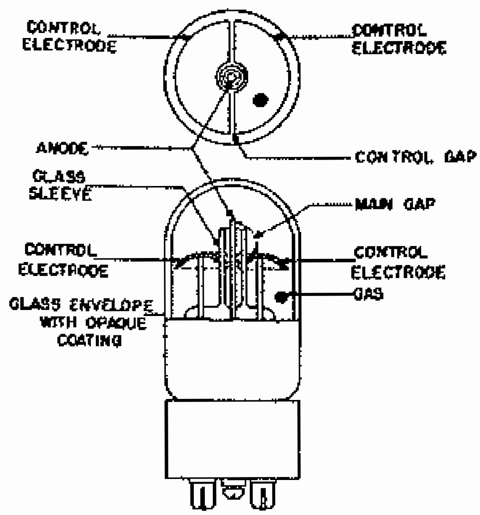


FIG. 24-2

is filled with a mixture of rare gases, mostly neon at low pressure. If a voltage is applied between the semi-circular electrodes and gradually increased, no current will flow until the breakdown voltage is reached, about 65 or 85 volts, when the tube suddenly becomes conducting.

Under this condition the gas is ionized in the tube and if the anode is at a positive potential greater than the sustaining voltage, it will also become conducting. To cause the anode to conduct current without first breaking down the gas between the semi-circular electrodes would require a voltage of about 130 to 200 volts between the anode and one of the semi-circular electrodes. Since the semi-circular electrodes are able to start conduction through the anode circuit with a lower voltage than required at the anode, they are called control electrodes.

Sometimes a distinction is made between the two control electrodes and the negative one is called the cathode and the positive one the control anode. The gap between the control electrode is called the "control gap" and the gap between the control electrode and the anode is called the "main gap". Because the control electrodes have activated surfaces and because their shape is not the same as the anode, the currents flowing in the main gap depend on the polarity of the anode. If the anode is positive, a large current may flow but if it is negative, much higher voltages are required to produce the same current. The anode will concuct only 1/20 as much current when it is negative as when it is positive.

3.02 A 55 volt battery is connected to the control electrodes in Figure 24-3 and the meter shows that no current flows.

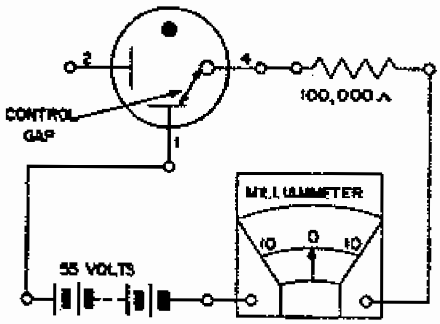


FIG. 24-3

3.03 A 70 volt battery is connected to the control electrodes in Figure 24-4 and the tube will ionize or "glow". The current flow is small, of course, because of the 100,000 ohm resistance. It is immaterial as to which of the control electrodes is positive.

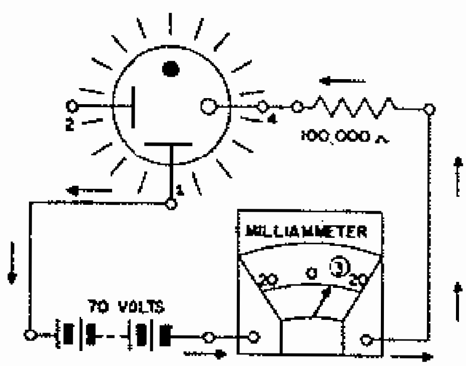


FIG. 24-4

3.04 It will be noticed that the positive terminal of the 85 volt battery in Figure 24-5 is connected to the anode and that no current flows.

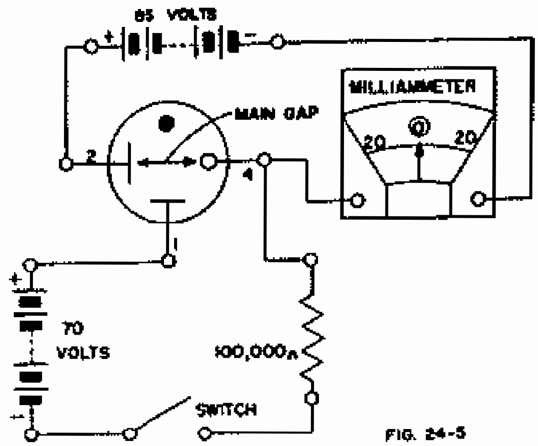


FIG. 24-5

When the control circuit is closed in Figure 24-6 the tube will ionize and current will flow across the control gap and then across the main gap to the anode through the main circuit.

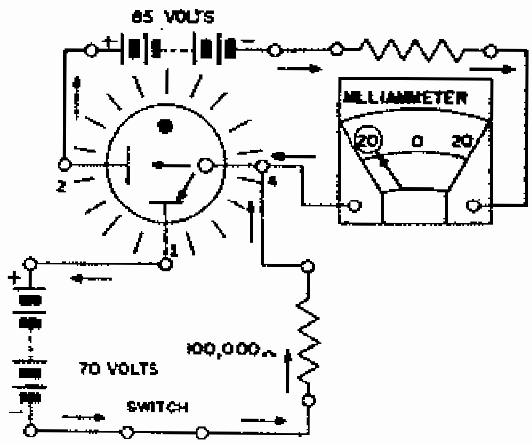


FIG. 24-6

If the main circuit battery is reversed so as to make the anode negative only 1/20 of the current will flow in Figure 24-7 as flowed in Figure 24-6.

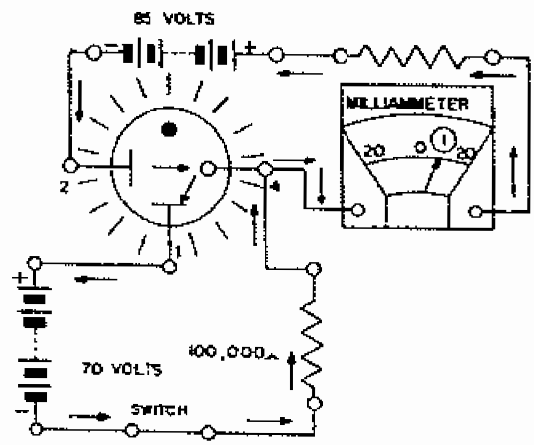


FIG. 24-7

4. Application

4.01 Figure 24-8 shows a 4 party subscriber circuit using cold cathode tubes.

Referring to Figure 24-8 and considering first the +Tip Party, if positive superimposed ringing current is applied to the tip, the ring being grounded, both tubes connected to the tip side of the line will break down and both will pass a very small current in their respective control gaps, this current being limited by the resistances.

At the +Tip station the ringer is poled to operate on positive current and since the anode is connected to the tip, the main gap will pass sufficient current to operate the ringer. At the -Tip station however, the tube has its anode connected to ground, which is negative, and it will not therefore allow any appreciable current to flow through the main gap of this tube and the ringer. Furthermore, the ringer is poled for negative current on the tip and will not operate on positive current.

From the foregoing it is evident that only the ringer at the +Tip station will operate and that the -Tip station draws very little current from the line. The ring stations are inoperative when current is applied to the tip side of the line as the ring side of the line is grounded.

4.02 When negative superimposed ringing current is applied to the tip of the line, ground being positive, the +tip station ringer will not operate since the main gap passes very little current and the ringer is poled against the current. Both tube and ringer at the -Tip station are however, poled correctly in this case and the -Tip station ringer will operate. The operation is similar for the ring parties when positive or negative superimposed ringing current is applied to the ring side of the line, the tip side being grounded. The operation of the ringers in this system is substantially that which would be obtained on pulsating currents, as the reversals in polarity of the A.C. ringing voltage are at too low a potential to affect the ringers even though they may in some cases be sufficient to cause a momentary discharge in the tube. For example, at the +Ring party station when negative superimposed ringing current is on the ring side of the line the anode of the tube at this station is at a negative potential equivalent to the effective voltage of the superimposed battery and during the positive cycle of the A.C. ringing current the effective potential across the main gap of the tube is roughly equal to the A.C. ringing voltage minus the voltage of the super-imposed battery which is ordinarily too low a voltage to cause a breakdown.

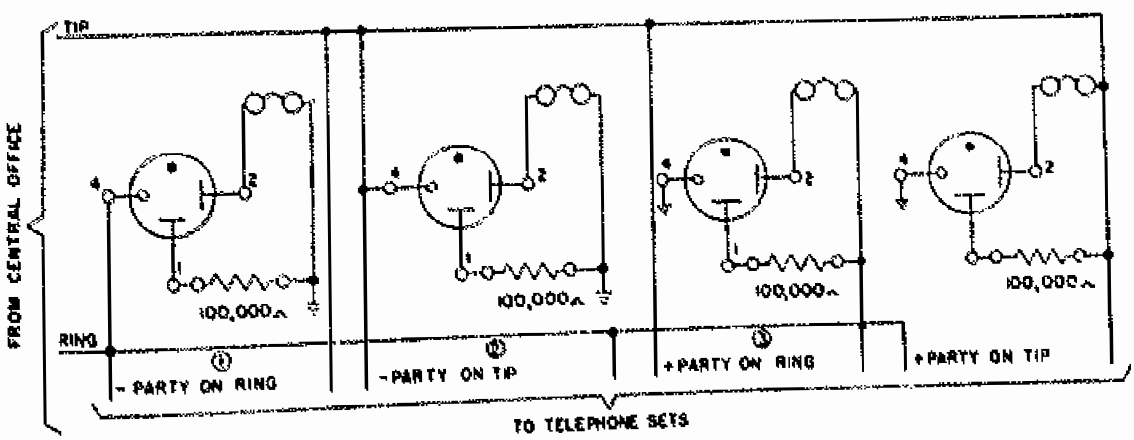


FIG 24-8

5. <u>Questions</u>

1. How many elements does a cold cathode tube have? What are their names?

2. What is the central electrode which projects through a glass sleeve called?

3. Why is the glass bulb coated with special black paint?

4. What is the bulb filled with?

5. What is the purpose of cold cathode tubes?

6. What do cold cathode tubes depend on for their operation?

7. Define "breakdown" "voltage".

8. Define "sustaining voltage".

9. Where is the "control gap"? Where is the "main gap"?

10. If the anode is positive does a large current flow?

11. Will the anode conduct only 1/20 as much current when it is negative as when it is positive?

CHAPTER XXV

PRINCIPLES OF TELEPHONE SIGNALING

1. Dial Functions

1.01 In a manual telephone system the subscriber tells the number he desires to an operator who selects the number for him and connects his line to the line of that number or who, in larger systems, connects the line to a trunk to a distant office and repeats the number he desires to another operator who selects the line for him. In automatic systems, the sequence of operations is somewhat similar but the operations are performed by electromechanical switches.

1.02 Since an electromechanical switch cannot respond to the voice of the subscriber as an operator can, it is necessary to provide a means for the subscriber to tell the switches what number he wants. This mechanism is the "dial" (Figures 25-1 and 25-2). Most people are now familiar with the operation of the dial. The subscriber puts his finger in the hole of the dial in which appears the letter or figure which he wishes to tell to the switches, pulls the rotating disc around until his finger strikes the stop and lets go.

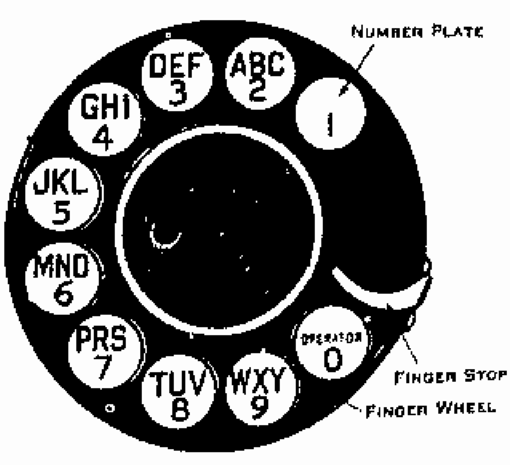


FIG 25-1

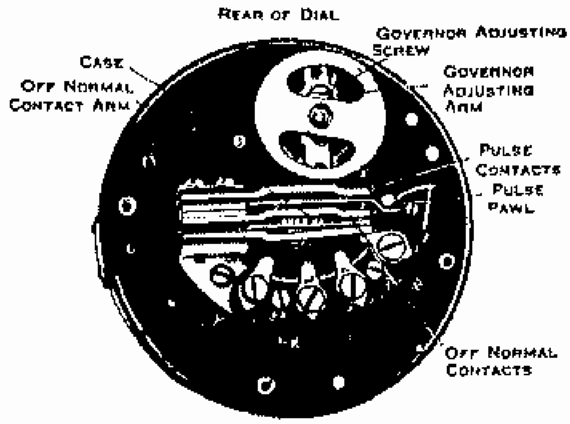


FIG-25-2

1.03 A spring rotates the disc back to its normal position and in doing so simply opens and closes the circuit of the subscriber's line the number of times indicated by the finger under the hole into which the subscriber puts his finger. It must be remembered that that is all the dial does -- it opens and closes the circuit of the subscriber's line a certain number of times. A little governor in the back of the dial controls the speed of the rotating disc and assures that the opening and closing of the circuit is uniform and regular. By performing this operation the proper number of times, the subscriber tells the switches the central office in which the desired line is located and the number of that line. It should be noted that rotating the disc with the finger in the hole marked "zero" opens and closes the circuit ten times. This, then, is the way in which the subscriber tells the switches what number he wants.

1.04 In Figure 25-3 the "line pulsing relay" is operated at the central office from a circuit through the primary winding of the 101A induction coil, the transmitter and the

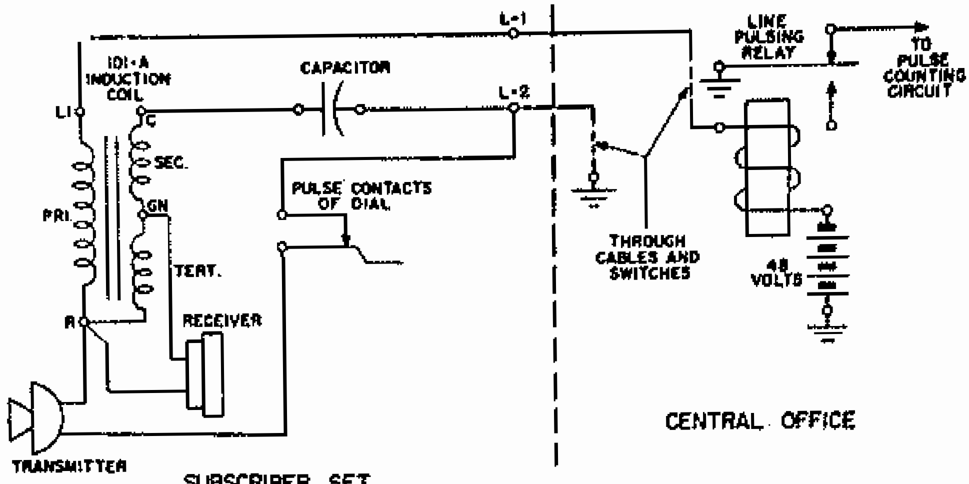


FIG 25-3

pulse contacts of the dial in the subscriber set.

If the subscriber wishes to reach the zero operator the dial in restoring to normal will cause the pulse contacts to open and close ten times.

The opening and closing of the dial pulse contacts will cause the "line pulsing relay" in the central office to release and operate ten times.

The "line pulsing relay" in releasing and operating ten times relays this information to the "pulse counting circuit" and automatic equipment functions to establish a connection to the zero operator.

In a similar manner other call combinations can be established.

1.05 With the pulsing circuit through the transmitter as in Figure 25-3 the life of the transmitter will be reduced.

To eliminate this condition the circuit is as follows: When the dial is moved off normal a pair of off-normal contacts in the dial make and the transmitter is shunted out of the pulsing path as shown in Figure 25-4.

1.06 In order to eliminate the dial clicks in the receiver when the dial is restoring to normal a pair of off-normal contacts in the dial break and the receiver is out of the circuit. After dialing is complete the off-normal contacts restore the circuit to normal.

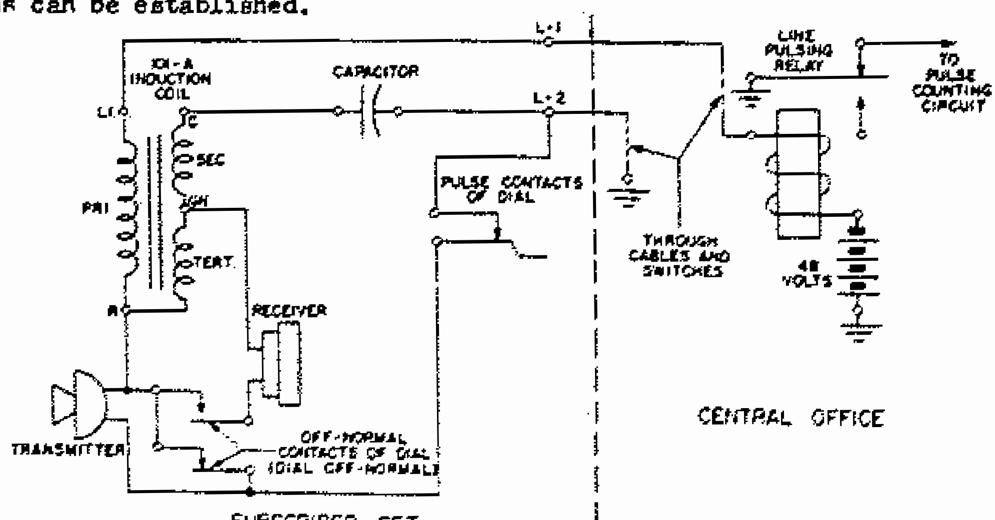


FIG 25-4

1.07 The average subscribers dial is designed to operate at about 10 pulses per second.

2. BUZZERS

2.01 Another telephone signaling device is the buzzer. There are two types of buzzers, A.C. and D.C. Figure 25-5 shows the circuit of a simple D.C. type buzzer. When the push-button switch is operated the current flows through the coils of the electromagnets, causing the armature to strike the pole pieces. This results in an audible sound.

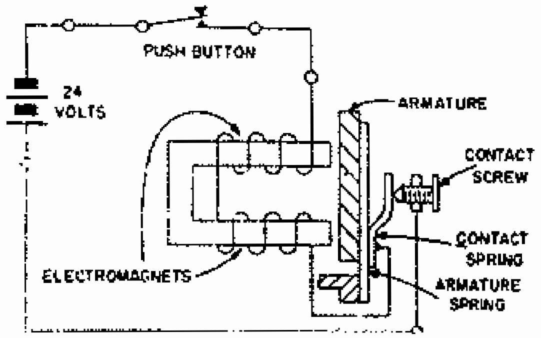


FIG. 25-5

As the armature moves to strike the pole pieces the electric circuit is opened at the contact and the electromagnets are demagnetized.

Demagnetizing the magnets allows the retractile spring to return the armature to its original position. When the armature returns it again completes the circuit - the magnets are energized - the poles are struck by the armature - the circuit is again opened at the contacts. This action is repeated rapidly resulting in an audible buzz.

2.02 Figure 25-6 illustrates a general purpose buzzer. This buzzer is arranged for either D.C. or A.C. operation. When operated on A.C. connections are made directly to the electromagnets. On D.C. the buzzer operates on self-interruption over its back contact in series with the windings. On A.C. the armature is moved by the voltage excursions each half cycle and returns to normal at the zero point of each half cycle. A.C. operation of a buzzer results in a sound which is a function of the A.C. frequency.

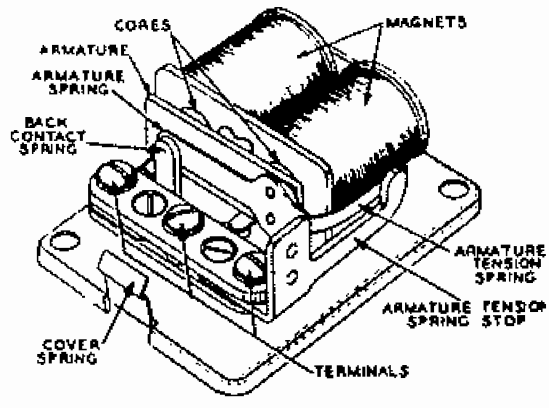


FIG 25-6

3. RINGERS

3.01 The telephone ringer or "bell" is used to indicate the presence of an incoming call. All ringers consist of two electro-magnets wound in series aiding and mounted on a strip of soft iron. The armature is pivoted beneath the magnets with a slight air gap between the ends and the respective magnet cores.

A permanent magnet is attached to the soft iron strip above the electromagnets and extends to a point underneath the armature. This permanent magnet by induction gives the cores of the electro-magnet a normal south polarity, and the ends of the armature a north polarity. The center of the armature, therefore, is a south pole. The diagram shown in Figure 25-7 illustrates the polarizing action of the permanent magnet.

3.02 In Figure 25-8 a clapper is attached to the armature so that at one end of the armature travel it will strike one gong, and at the other end of travel it will strike the other gong. The armature is normally held in the position shown by the spring known as a biasing spring. When current flows through

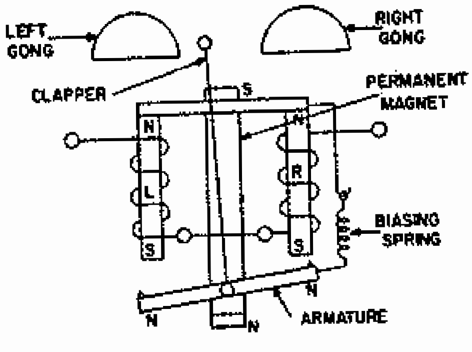


Diagram illustrating action of a ringer.

FIG. 25-7

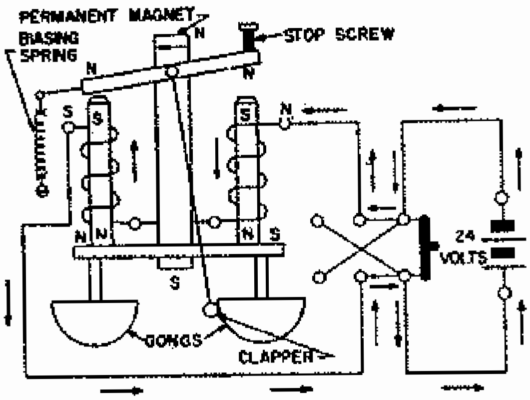


FIG. 25-8

the coils in the direction shown, the armature is merely pulled tighter against the stop screw. When the current flows in the direction shown in Figure 25-9 the armature is rotated until the clapper strikes the gong on the opposite side. When the circuit is opened, the spring rotates the armature to its normal position and the clapper strikes the gong on that side. (Figure 25-10) By successively opening and closing the switch in the proper direction, the bell may be made to ring.

3.03 In Figure 25-11 current is flowing from Battery "A" through both windings to ground, as indicated by the arrows. The flow through ringer 1 is in the direction to cause it to operate, but ringer 2 is connected reversed so that its armature is merely pulled harder against the stop screw.

Thus, when key "A" is opened and closed ringer 1 will operate, but

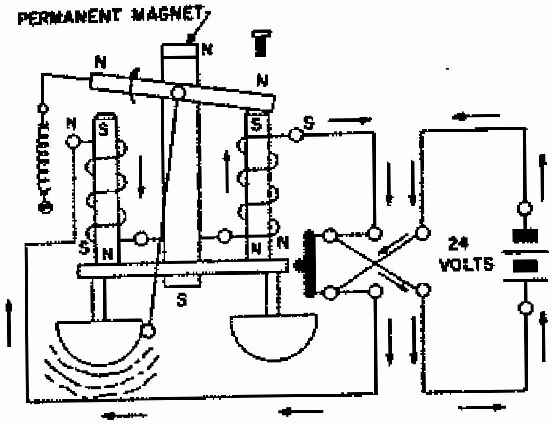


FIG. 25-9

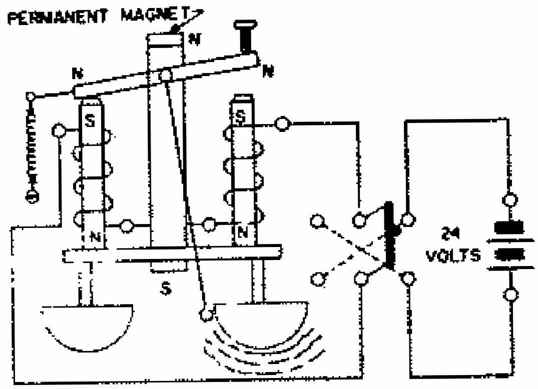


FIG. 25-10

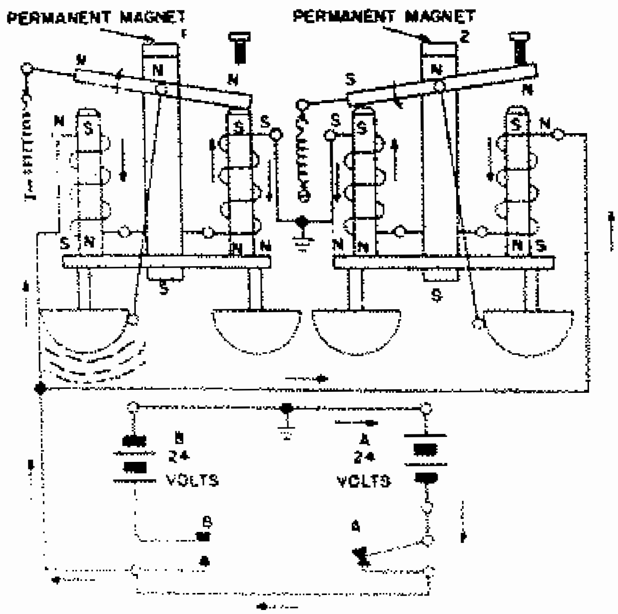


FIG. 25-11

ringer 2 will remain silent. However, battery "B" is connected reversed as compared to battery "A", so that when key "B" is opened and closed ringer 2 operates and ringer 1 remains silent. (Figure 25-12)

Table 1 indicates the effect in each ringer when either battery is connected. Such ringers are said to be polarized.

	Ringer 1	Ringer 2
Battery "A"	Operates	Current flow in wrong dir.
Battery "B"	Current flow in wrong dir.	Operates

Table 1

From the preceeding paragraphs it is evident that one bell or another may be selected for ringing by the polarity of the battery applied. This polarity is sometimes designated as positive or negative current. In actual practice the battery and key combinations illustrated in Figures 25-11 and 25-12 are replaced by super-imposed negative and positive ringing current. (Chapter XXIII)

3.04 Two types of ringers are in use today. They are the unbiased ringer and the biased ringer.

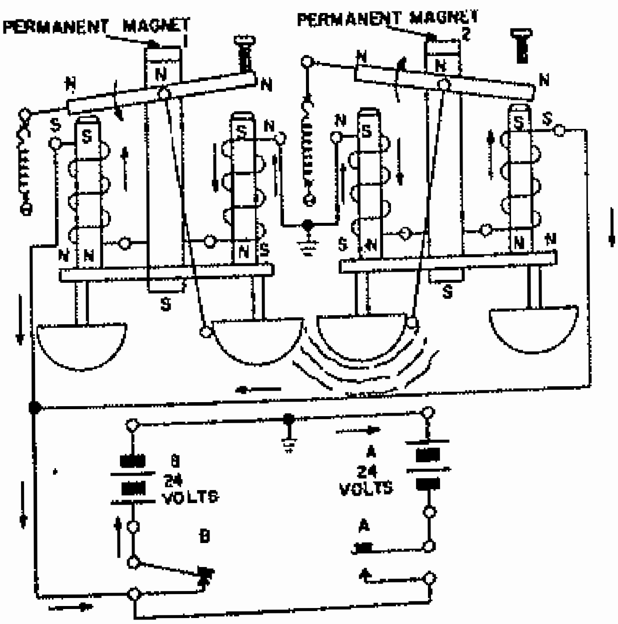


FIG. 25-12

3.05 Unbiased ringers are intended for use on alternating current only. When alternating current passes thru the magnets, the magnetism set up by the permanent magnet is strengthened in one coil and diminished or overcome in the other on the first half cycle. The armature now tilts toward the core having the strongest magnetism and the clapper ball strikes one gong. As the current is reversed on the next half cycle, the other coil has the greater attraction and the clapper ball strikes the other gong. See Figure 25-13 which shows an unbiased ringer.

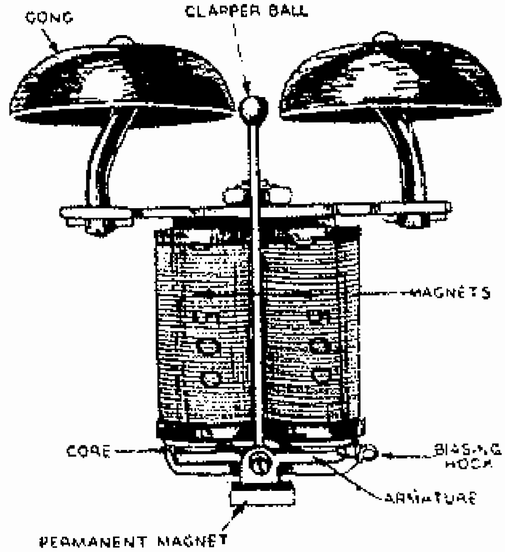


FIG. 25-13

3.06 The biased ringer is used in all cases where super-imposed current (direct current superimposed on alternating current) is used for ringing. The biased ringer is constructed like the unbiased ringer except that it is equipped with a biasing spring to hold one end of the armature against the respective magnet core. See Figure 25-14. A pulse of the proper polarity will overcome the pull of the spring and pull the armature against the other core, ringing first one gong and then the other as the armature is released and returned to the biased side. Pulses of the opposite polarity would, of course, have no effect on the ringer. This makes it possible to ring either of

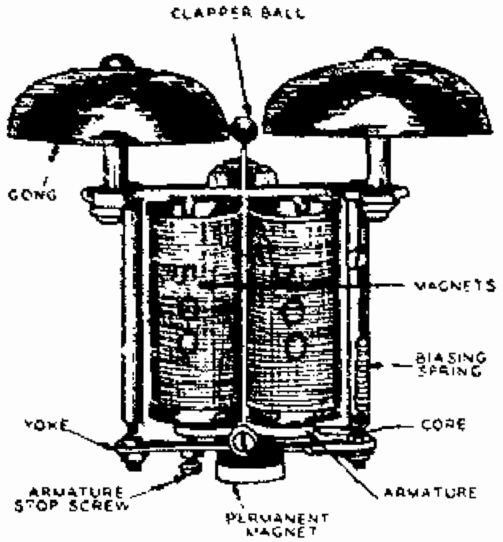
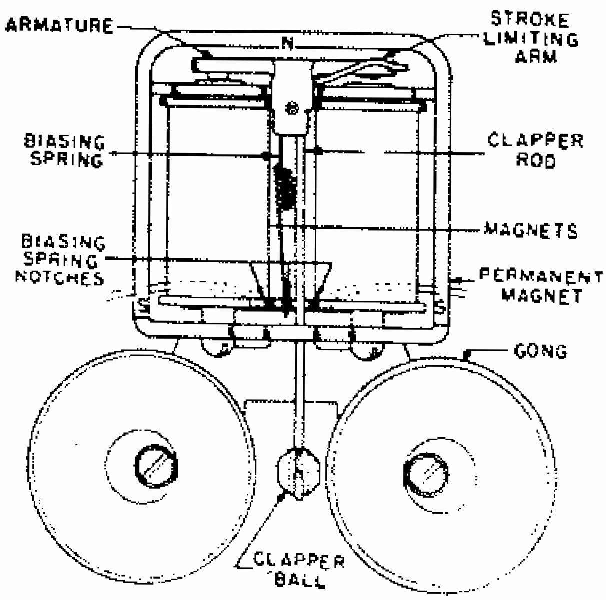


FIG 25-14

two ringers on one wire by choosing the polarity of pulses to be sent out or any one of four parties when two ringers are rung from either side of the line as in the case of the four party full selective system.

3.07 A biased ringer of a more recent design, coded B1A, is shown in Figure 25-15. The permanent magnet of this ringer is U shaped and the conventional retractile spring has been replaced by a cantilever type biasing spring arranged for 3 different tension settings. The gongs on this ringer are mounted vertically and are provided with excentrically located mounting holes for obtaining the necessary clearance between the gong and the clapper ball. B1A ringers are principally used in telephone set mountings and in telephone sets.



B1A RINGER

FIG 25 - 15

4. Individual Line Ringing

4.01 Individual line ringing is the process of signaling one subscriber. Figure 25-16 illustrates the ringer connection for an individual line. Superimposed ringing current is applied across the tip and ring of the individual line. The capacitor in series with the ringers block the D.C. and the ringers are energized by the A.C.

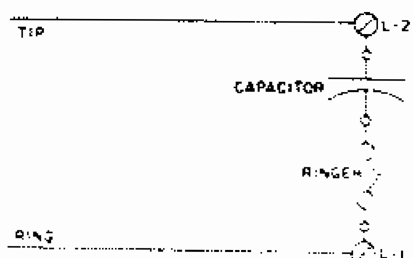


FIG 25 - 15

5. Two Party Selective Ringing

5.01 Two party selective ringing is the process of signaling either of two subscribers on a line. Figure 25-17 illustrates the ringer connections for a typical two party selective line. To signal the tip party superimposed ringing current is applied across the tip of the line and ground. To signal the ring party superimposed ringing current is applied across the ring of the line and ground.

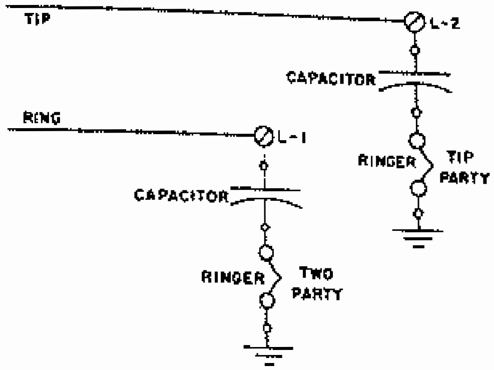


FIG. 25-17

6. Four Party Semi-selective Ringing

6.01 Four party semi-selective ringing is the process of signaling more than one subscriber on a line. Figure 25-18 illustrates the ringer connections for a typical four party semi-selective line. To signal parties 2 and 4 superimposed ringing current is applied across the tip of the line and ground. To signal parties 1 and 3 superimposed ringing current is applied across the ring of the line and ground.

6.02 In order that only one party responds to the signal coded ringing is used. Coded ringing is process of applying one long pulse or two short pulses of superimposed ringing current across the tip or ring of the line and ground. In four party semi-selective service two parties will hear coded ringing, but only one party will respond depending upon the code.

7. Eight-Party Semi-selective Ringing

7.01 Eight party semi-selective ringing is similar to four party semi-selective ringing with the exception that four ringers are connected from each side of the line to ground. In signaling a subscriber coded ringing is used.

8. Four-Party Full Selective Ringing

8.01 A complete description of four-party full selective ringing is given in Chapter XXIV, paragraphs 4.01 and 4.02.

9. Questions

1. Briefly, how does a telephone dial convey the desired telephone number to the central office equipment?

2. Will an A.C. buzzer operate a D.C.?

3. Will a D.C. buzzer operate an A.C.?

4. What two types of ringers are in use today?

5. When is the biased ringer used?

6. Describe individual line ringing.

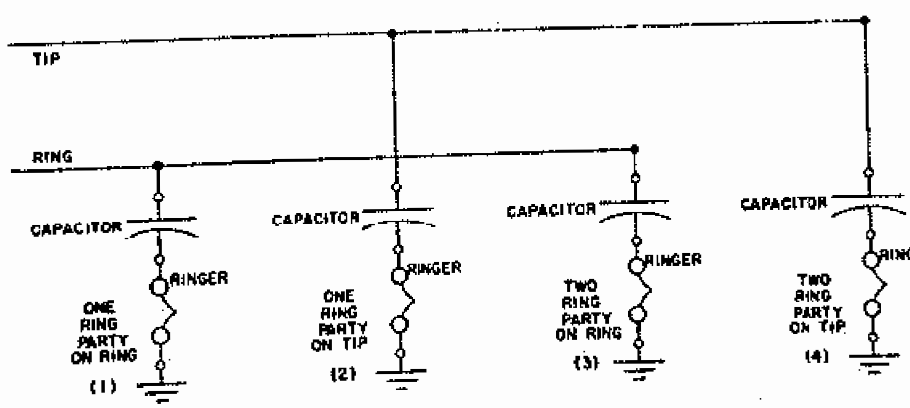


FIG. 25-18

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