Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

AN INTRODUCTION TO ELECTRONICS, RADIO, AND TELEVISION

ASSIGNMENT 1

UEL

HARVEY MOEHL

Subj: **Re: FRIDAY EVENING**
Date: 10/06/2000 10:39:32 PM Pacific Daylight Time
From: JPBBOT
To: Moehlhj

Hi Harvey----I remember Bessie Stratton Clancy very well. I have not heard from Ray or Donna either but thought they were lazy as myself as I don't get on the computer that often anymore. I got on tonight and had many jokes to read and a few letters from friends. Our weather has been ideal. The early AM in the 60's and the high during the day in the high 80's or low 90's which to us is just right. I guess living in a hot dry climate like we have does thin your blood somewhat as we take a sweater or jacked to the casino's when we go there as it is to cold for us as we think they keep the air conditioning down too low. We can tell the tourists as they are walking around in shorts. I wouldn't doubt that Ray and Donna went back to Illinois. They sounded like they wanted to go back to see the great grand child as well family there. I am surprised that Donna or Ray did not e-mail either one of us as they usually are good about doing this. I guess we will hear from them when they return. Glad they had no problem with the brush fire and that is all over with. I see where Denver has had snow already so no doubt Ray and Donna have already seen the white stuff. We will see it up in the mountains in anoter month or so Sounds like you will shortly be looking for another household project now that your windows are finished. I just look lthe other way. Everything here seems OK. I do have some cactus to replace (very carefully) and we are going out tomorrow to a garden supply to see what we can find. We don't usually do much on the week-ends, however we are usually busy during the week. We are getting involved at present with helping our daughter pack and get ready to move. It looks like she sold her condo. It is in escrow and she is going to move into an apartment while she looks for a home. She is tired of condo living and wants a 3 bedroom home with a yard of her own and a garage. I told her to take her time and spend time looking not only at the home but the location also. I hope she listens. She does have a 3 month lease on the apartment and she then can rent from month to month until she finds what she wants. I try to advise her not to hurry but sometimes they ask for advice and then do what they want anyway. Write when you have time. I will eventually answer when I finally get on the computer.
Joe

ACKNOWLEDGEMENT

The preparation of the Electronics, Radio, and Television information which is included in this Training Program would not have been possible without the help of a large number of organizations and individuals.

In particular, United Electronics Laboratories gratefully acknowledges the cooperation and assistance of the Crosley Division of AVCO Manufacturing Company, the Radio Corporation of America (RCA), the Philco Corporation, Motorola, Incorporated, the American Broadcasting Corporation, the Columbia Broadcasting System, the Canadian Broadcasting System, the DuMont Television Network, and the National Broadcasting Company.

Assignment 1

AN INTRODUCTION TO ELECTRONICS, RADIO, AND TELEVISION

You took possession of a key to one of the most interesting, respected, and well-paid professions in the world when you decided to enter the field of Electronics. Your key to this "new world" will be your knowledge of electronics--how electronic equipment operates, how defective parts affect this equipment, how to repair and maintain it. This knowledge will enable you to service, operate, and maintain the wide variety of electronic, television, and radio equipment which plays such a vital part in our present-day civilization.

When you meet a new person in everyday life, the first step in your becoming acquainted is an introduction. Similarly, the first step in your becoming acquainted with electronics is an introduction to it, and to its "close friends" radio and television. That is the purpose of this first assignment in the training program--to introduce you to electronics, radio, and television.

History of Communication

Since the days of the stone age, man has tried to send messages over ever-increasing distances. The first "long distance transmission" was probably a shout. However, the primitive man soon learned that greater distances could be spanned by beating on a hollow log with a club. In some primitive tribes, even today, this system of communication is still employed.

Of course, the use of sound is not the only method of communication. The sense of sight has also been used since the time of the cave man for sending information from one point to another. As the cave man waved his hand in a greeting to his fellow creature on the other side of the valley, he was using this method of communication. As time passed, sight communication was improved through the use of puffs of smoke, lanterns, and fires, and the waving of flags. Some of these systems, too, are still employed in modern communications--for example, the landing signal flags used aboard aircraft carriers.

All of the methods of communication which have been mentioned so far have the same fault in common. The distance over which they are effective is quite limited--ranging to a few miles, at best.

Although man yearned for long distance communication for thousands of years, it was not until less than 150 years ago that a step forward of any importance was made. In 1832, when Samuel F. B. Morse invented the electric telegraph, the distance of communication was extended "beyond the horizon." By operating a telegraph key, he controlled the flow of electrical impulses along a wire, which, in turn, caused a telegraph "sounder" at the other end of the wire to operate, producing clicks which could be heard. By means of code, these clicks could be translated into letters and words. The growth of the telegraph was rapid, and in approximately 30 years telegraph messages were being sent from America to Europe by means of an underseas cable.

The next stride forward in communications took place in 1875, when Alexander Graham Bell invented the telephone. In this device, with which everyone is now familiar, electrical impulses were again used, but a reproduction of the speaker's voice, rather than the clicking of a sounder, was heard at the opposite end of the line. Thus, a spoken message could be sent over hundreds of miles.

Although the telegraph and the telephone could carry messages over hundreds of miles, they were both limited in the same way. They could carry these messages only where it was possible to string wires. Thus, it was not possible to communicate with remote areas, with ships at sea, with balloons, or, a little later, with airplanes. It was obvious that a means of communication was necessary which did not require the use of wires--in other words, wireless telegraph and wireless telephone.

A few years after the invention of the telephone, a young German scientist, Heinrich Hertz, experimented with the first form of wireless telegraph. He sent radio waves and picked them up across the room with a very crude receiver. Many other scientists and experimenters worked in the development of Hertz's crude "wireless" telegraph system, and shortly after the turn of the century Guglielmo Marconi succeeded in sending the first message across the Atlantic Ocean by means of radio waves. Further development of the radio system resulted in wireless telephone communication, which was then developed into radio broadcasting, as it is known today. Thus, communication over thousands of miles without wires became a reality and helped make possible many other scientific developments of the Twentieth Century.

Miraculous as it is, radio did not fully satisfy the needs of the general public. Because we are gifted with sight, it is only natural for us to desire our entertainment "dished up to us," so that we can see it as well as hear it. Consequently, while some scientists and inventors worked to improve radio, others were working just as hard to develop a system whereby pictures could be "transmitted through space." The final development of this system is, of course, TELEVISION, as we know it today.

It might be well to point out that television is not the result of any one person's work or creative genius. Instead, it represents the work of many scientists, inventors, and experimenters. The first television pictures were transmitted from Whippany, New Jersey, to New York City, by Dr. Herbert Ives, in 1927. These were very poor images, and it was not until 1946 that television transmitting equipment and receivers were perfected to a great enough degree to make commercial black-and-white television broadcasting practical.

Color television also passed through a long period of development before its final acceptance. The first colored television pictures were transmitted by Dr. Ives and his associates in 1929. These pictures, although realistically colored, were about the size of a postage stamp. Many systems were devised to enable larger color television pictures to be telecast, but it was not until 1953 that a truly suitable color television system was available to the general public.

Thus, in a span of less than 150 years, man was able to accomplish what he had dreamed about for thousands of years--the transmission of sound and sight (in full color) over long distances. Color television is the fulfillment of that dream.

Radio, Television, and Electonic Services

Let us now look at some of the "parts," or divisions, of the Electronics field. As a starting point we'll first consider radio. When we hear someone speak of radio, we naturally think of radio broadcasting, since this field is familiar to all. Actually, the radio field includes many services in addition to radio broadcasting, as will now be explained.

Radio Broadcasting

In the ordinary usage of the term, radio broadcasting suggests the broadcasting of entertainment, news, etc., for the benefit of the general public. There are several ways in which this is done. The first of these, and the most widely known, occurs in the "Standard Broadcast Band" which is received by millions of home and auto radio receivers daily. Everyone familiar with radio is familiar with this service. Figure 1 shows one of the outstanding broadcast stations now in operation.

There are also short-wave radio broadcast stations, which serve primarily to broadcast entertainment from stations in this country to other points throughout the world. These stations are small in number compared to the standard broadcast stations.

Another radio broadcast service is rendered by the Frequency Modulated stations. These stations transmit entertainment and operate on the short waves, but, as they operate on an entirely different principle than the short-wave broadcast service which has been mentioned, the programs are not "carried" great distances. Instead, each station serves an area close around it, within a radius of approximately 50 miles.

Two-Way Police Radio

Almost all police forces now have two-way radio equipment to provide communication between the headquarters and the patrol cars out on the streets or country highways. The patrolmen in the car are able to talk to headquarters, and in addition most systems permit direct communication between the individual cars.

Two-Way Aircraft-To-Ground Communications

All commercial aircraft and many private aircraft are equipped with two-way radio communication equipment. This enables the pilot to receive weather reports, landing instructions, etc., from ground stations during flight, and it also permits the pilot to report his position at regular intervals. Figure 2 shows just a small part of the radio equipment aboard a Pan American DC-4 aircraft.

Miscellaneous Two-Way Communications

Two-way radio communications systems are now being used by hundreds of different services and industries. Among these are: taxicabs; busses; truck lines; water, gas, and electric utility companies; railroads; garage and wrecker services; road maintenance departments; pipe lines; and delivery services.

Instrument Landing Equipment

Commercial airliners are equipped with radio devices to enable the pilot to land the plane during heavy fogs, rains, or other conditions which would make sight landing impossible. In addition, radar equipment is being used in some of the leading airports.

Radio-Telephone Communication System

There are two separate services under this heading. One of these has been highly publicized and has had widespread use. It consists of a radio link between cars and the Bell Telephone System. By means of this system, a busy executive may conduct normal telephone conversations while in his car. This service is proving of great value to professional and business men. The other radio-telephone service is used in handling long distance overseas telephone communications. Until just a few years ago, these messages were handled entirely by undersea cables.

Radio-Beacon Equipment

This equipment is used to guide planes in the air. The radio waves are concentrated into "beams," and the airplanes fly along these beams, just as a car follows a highway. Other radio signals in the beacon system tell the aircraft pilot when he is a few miles from the airport and when to start his landing glide.

Loran Equipment

This is a system somewhat similar to the radio-beacon. It is used as a navigational aid for ships at sea.

Micro-wave Relay Systems

Micro-wave relay systems are used, in place of a coaxial cable, by the Bell Telephone System to relay television signals. They are also used by pipelines, by railroads, and by many other industries. A micro-wave relay system is actually a radio link which can be used to accomplish the same results as several, several dozen, or even several hundred telephone wires. In this system the radio energy is beamed from one relay station to the next, where it is power-boosted and beamed on to the next, etc. The type of communication which is passed along depends largely on the use of the relay system. For example, such a system can be used to pass along orders from a central location to points hundreds, or thousands, of miles away. At the same time, the system could be used for controlling devices at remote locations. For example, in a pipeline installation a single dispatcher can control valves at desired points along the pipeline, although it might stretch for hundreds or thousands of miles.

Government Services

Many motion pictures and plays have illustrated the use of radio communication by the Army, Navy, Marine Corps, Coast Guard, and Air Force. In modern warfare, this type of instantaneous communication is an absolute necessity. There are, however, many other types of government radio installations. Included among these are Meteorological aids, Forestry Service, and Bureau of Standards.

Facsimile

Facsimile is a form of communication which has not, as yet, developed to a great degree. It is a system whereby newspapers, photographs, or other printed material are transmitted by radio. The facsimile receiver has a device called a printer, which reproduces the transmitted copy--newspaper pages, photographs, etc.--on a roll of paper.

Radar

Radar is a specialized form of radio transmission which was developed during World War II. Its chief wartime use was in detecting and accurately determining the range of enemy aircraft. It has, however, found widespread use in the commercial field since its wartime secrecy was lifted. Radar installations aboard commercial airliners continuously plot a "map" of the terrain over which the plane is flying, and can also be used to determine the extent of storms into which a plane is flying. Many of the leading airports are equipped with radar landing equipment. Practically all ocean-going passenger vessels employ it as a navigational aid. A great majority of the boats on the Great Lakes and large rivers in the United States use radar, so that they can continue their operations in spite of rain or fog. Figure 3 shows a radar installation aboard the Dutch Lines palatial passenger ship NIEUW AMSTERDAM, and Figure 4 shows a technician adjusting radar equipment before it is to be installed on shipboard. Another widely known use of radar is as a speed checking device. Signs stating: WARNING - SPEED CHECKED BY RADAR are becoming almost as common along the nation's highways as the old familiar one - WARNING - DANGEROUS CURVE.

Televison Broadcasting

Television is, of course, the transmission and reproduction of a view, or a scene, especially a view of persons or objects in motion, by means of radio waves. In addition, the sound which is associated with the scene is transmitted. Television transmission can be of such nature that the reproduced scene appears as a black-and-white picture or as a full-color reproduction of the original scene.

Industrial Television

Industrial television is one of the most rapidly developing branches of this fantastically expanding field. Industrial television is the use of TV cameras and receivers for purposes other than tel-vision broadcasting. For example, industrial television enables the operator of a steel mill to "see" at close range the progress of the red-hot steel as it moves through the mill, while he is seated in an air-conditioned control booth. It permits the highway department to observe the flow of traffic throughout the entire length of the tunnels on the Pennsylvania Turnpike. It makes it possible for the scientist in an atomic energy laboratory to "watch," from a safe distance, the action of deadly radioactive materials. Through the application of industrial television, a department store may exhibit special items at many points throughout the store. Industrial TV can be used to check the operation of conveyors in industrial plants, to observe the movement of freight cars in railway switchyards, and to permit one professor, or instructor, to lecture to any number of classroom groups simultaneously. Industrial color television is proving to be of great value in teaching surgery to young M.D.'s. New uses for industrial television are being found daily. Obviously, it is impossible to list more than a fraction of its uses in this assignment.

Electronics

Electronics is a very general term which is applied to equipment using vacuum tubes and other radio parts, but which does not transmit radio waves through space. Electronics can be used to do many different things, such as sort fruit, check the purity of drinking water, regulate the heat of ovens in industrial plants and steel mill smelting furnaces, cook hamburgers, compute at speeds thousands of times faster than humans (See Figure 5), operate juke boxes, check the color of dyes in cloth manufacturing plants, count the number of cars passing a point on the highway, control chemical and mechanical processes, etc. The list is almost endless, so wide is the use of electronics in our modern life. Electronics is found in the home, in industry, in government (electronic "brains" and electronic filing systems), in defense--even in our sleep! One of the newer electronic devices enables a person to learn while sleeping.

Facts and Figures

Let us look at some facts and figures. In the last year before World War II, there were 56 million radios of the home entertainment type in use in this country alone, and there were 9 million radio receivers installed in automobiles. There were 4,300 aviation radio ground transmitters and nearly every airplane, from the smallest to the largest, carried from 1 to 8 radio receivers, as well as one or more transmitters. There were 2,217 police radio stations, and over 1,200 manufacturers of radio parts, tubes, and equipment.

Since the war, the radio, television, and electronic industries are enjoying an expansion so great that even the most enthusiastic supporter would have called it fantastic just a few years ago. Electronic developments from wartime research have opened new fields, which are making the prewar radio industry look like small business.

In April 1952, the Federal Communications Commission made official channel allocations for 2,053 Television stations, and when they began reprocessing station construction permits, there were but 108 TV stations on the air. Within a year-and-a-half period, this number had more than tripled, and the construction of new TV stations is still expanding rapidly in all sections of the country. Coaxial cables and associated micro-wave relay links were extended so that the nation is spanned from coast to coast. Figure 6 shows one of NBC-TV's large studios in New York City and Figure 7 shows CBS-TV's Television City in Hollywood. The increase in TV receivers has been almost unbelievable. The "mere handful" in 1947 has increased to more than 43 million at this time. The current volume of radio and TV sales is one billion, two hundred million dollars annually, and the annual radio and TV service bills total one billion, five hundred million dollars. It is estimated that by 1965 the electronics field will be an eleven-billion-dollar-a-year industry.

Don't attempt to burden yourself by learning any of the facts and figures which have been quoted in the few paragraphs above. They have been included only to give you an idea of the tremendous opportunities in this field.

Why Train For Electronics and Television?

In the early days of radio broadcasting, radio receivers were so simple that nearly everyone built his own and kept it in repair himself. In fact, for many years anyone with a good pair of eyes and the simplest of tools and test equipment could successfully set himself up in business as a radio service man. He had to know little or nothing about the "theory" or principles upon which radio worked. However, as radio receivers were improved they became more complicated. As a result, only the technician who understands and can use his knowledge of the theoretical side of radio principles has an interesting and profitable future before him. In service work "time means money." The technician who knows the underlying principles and can get to the heart of the trouble quickly will be able to make much more money than will the man who fumbles along until he finally stumbles on the trouble.

A knowledge of technical theory is even more important in radio broadcasting where just a few seconds of silence, or being "off the air," can cost the station or network hundreds or thousands of dollars. Broadcasters, then, rightly insist on hiring technicians who are technically qualified and who are quick thinkers.

If technical ability and training are important in radio, they are much more important in television. The reason for this is that, although radio and television use many of the same fundamental principles, television is a great deal more complicated. The average radio receiver has five vacuum tubes, whereas television receivers use from 15 to 40 tubes.

Industrial electronics, too, requires thoroughly trained technicians. In industry, electronic equipment is usually used to control the most critical part of the entire process. Thus, the electronic equipment is, in effect, the supervisor which regulates the machine that, in turn, replaces the skilled worker. Quite obviously, the technician who adjusts and maintains this "supervisor", the electronic equipment, must be a completely qualified electronics technician.

This training program has been designed especially for persons who must take their training at home, usually after their regular hours of work. The Home Laboratory Experiments and the assignments covering the theoretical side of electronics, radio, and television were developed with this viewpoint in mind. Each new subject is started at its most basic point and then developed fully. This eliminates any misunderstanding that might arise, if it were assumed that anything about the subject was "common knowledge." Then a step-by-step training method is used to give the trainee the full information he needs about each subject. We try to anticipate all questions and give the answers in the assignments. Our Consultation Service is set up to help solve any and all radio and television problems for the Associate.

The Radio System

Electronics and television had their beginnings in radio. It will be of benefit, therefore, to look behind the scenes of a radio broadcasting system to find out just what takes place.

Radio makes it possible for a person to speak at one particular point and be heard in hundreds or thousands of other places scattered "all over the face of the earth." This miracle has become so commonplace that everyone accepts it, yet few understand how it takes place. In our brief look at a radio broadcasting system, we'll try to find out just how this miracle is brought about. In this first glance at the radio system, we will, of course, run across a few technical terms. Don't let these terms bother you at this time. You will obtain a full understanding of them as you advance through the training.

Radio is, of course, a means of transmitting "sound" from one point to another. We all know that it is possible to transmit sound waves directly--for example, one person speaking to another. The sound waves caused by vibrations produced by the vocal cords of one person travel through the air to the ear of the other person and cause the sensation known as sound. As mentioned previously, such a system would not be suitable for broadcasting because of limited range. Sirens, bells, and whistles can at best be heard over a distance of a few miles, while the maximum range of voices and musical instruments is a few hundred feet.

Since radio is a means of transmitting "sound" from one point to another, let us pause long enough to find out a little more about sound before proceeding with the radio broadcasting system. We are all familiar with the effects of sound because we are able to hear it, but at this time we wish to find out what sound is, and how it travels from its source to the ear.

Sound Waves

Sound waves are set up by a vibrating object. For example, as a bow is passed across the strings of a violin, the strings vibrate and produce sound waves. As a musician blows into a saxophone, the reed in the instrument vibrates. As we speak, the air passing through our vocal cords causes vibrations. All of these vibrations produce sound waves in the air.

To see just how the sound travels from the vibrating object to the ear, we will consider the loudspeaker in a radio receiver. There is a large paper cone in an ordinary loudspeaker (as may be observed in Figure 8), which vibrates back and forth when the radio is operating. This vibrating cone alternately pushes and pulls on nearby particles of air, and sets the air particles into vibration.

As the cone of the loudspeaker pushes forward, it shoves the air particles in front of it. This sets up a region of higher air pressure than normal in front of the speaker cone. One of these high pressure regions begins to travel away from the loudspeaker each time the speaker cone moves forward.

As the cone of the loudspeaker moves backward, it leaves more room in front of it than previously for the air particles. This creates a partial vacuum in front of the speaker. This partial vacuum, or lower than normal air pressure region, travels outward from the speaker in front of a new high-pressure region each time the speaker cone moves forward.

This process repeats itself each time the loudspeaker cone moves forward and backward, which happens many times a second. The resulting regions of higher and lower air pressure, traveling away from the source, are known as sound waves. (This may be seen in the sketch of Figure 9.)

It should be mentioned that when a sound wave reaches the ear, the air particles have not traveled from the speaker cone to the ear. A sound wave is made up of vibrating air particles and might be compared to a wave moving across the surface of a lake. The wave travels across the lake but the water particles do not. They merely vibrate up and down. The water particles stay in practically the same position all of the time, and only the vibrating up and down motion travels across the lake. In a like manner, air particles in a sound wave do not move very far; they merely move back and forth in a certain area. Each particle transfers its back-and-forth motion to the next particle. This forms traveling regions of high and low pressure, which are sound waves. The sound waves travel at a speed of approximately 1,089 feet per second.

As sound waves strike the ear drums, they cause the ear drums to vibrate. The vibrations of the ear drums are conducted to nerves which transmit the sensation of sound to the brain.

In addition to its limited range, there is another disadvantage to the use of sound alone for broadcasting. If several persons are talking at the same time, we have no way of listening to any one of them and "shutting out" all of the others. Nature has not equipped us with any means of selecting or "tuning in" the particular person we wish to hear. This suggests another great advantage of the use of radio waves for broadcasting. Although there are thousands of stations broadcasting at the same time, the person operating his radio receiver can tune in one desired station and, in so doing, shut out all of the others.

The Radio Station

Now that we know a little about the nature of sound, it will be possible to proceed with a discussion of "what happens at a radio station." The program usually originates in the studio, as shown in Figure 10, and in the sketch of Figure 11 which illustrates an entire radio broadcasting system. The performance is conducted before a microphone which receives the sound waves set up by vibrations of the vocal cords of the performers and the reeds or strings of musical instruments. The microphone operates on the same principle as the mouthpiece of a telephone. The sound waves cause a diaphragm (a thin metal or foil disc) in the microphone to vibrate and the microphone generates electrical waves in the circuit to which it is connected. These electrical waves correspond to the sound waves striking the microphone and are called audio signals.

The audio signals are actually sound waves in an electrical form. These audio signals are very weak and must be "built up," or amplified, before they can be used further. They are carried by cable from the microphone in the studio to the control room, where they are amplified by vacuum tube circuits called audio amplifiers. The action of audio amplifiers will be explained in detail later in the training program.

A technician, called the control operator, operates the control console in the control room of the broadcasting station we are "visiting." A control operator may be seen at the control console in Figure 12. It is his job to regulate the volume of the audio signal so that it will always be between certain specified limits, as indicated by a meter on the control console. The operation of controlling the volume is called "riding the gain" by radio and television broadcast personnel.

If the program consists of a variety show or of music by an orchestra, where several microphones are used, the control operator blends the outputs from the various microphones to obtain the desired effect. He also controls the switching of programs from local studios to "chain" programs, electrical transcriptions, etc. Chain programs originate in studios located in New York, Chicago, Hollywood, etc., and are sent to the local stations all over the country through telephone lines. Electrical transcriptions are similar to phonograph records and are played on specially designed, high-quality turntables.

The amplified audio signal is next carried to the transmitter. The transmitter may be located very close to the control room or it may be located several miles outside the city. In the latter case, telephone lines are used to carry the audio signal from the control room to the transmitter. At the transmitter the audio signal is further amplified and at this point may be amplified, or built up, so much that it is a million or more times as strong as when it left the microphone! In spite of the strength of this audio signal, it cannot be applied to an antenna and transmitted through space. This is because the audio signal is not actually a radio wave. To be transmitted through space the audio signal must be combined with a radio wave called the "carrier." The carrier transports the audio signal through space to radio receivers.

Block Diagram

Figure 13 shows a simple block diagram of the radio system we have been discussing. The sound waves, microphone, and audio amplifiers which have been mentioned can be seen. Also, in Figure 13, a block will be noted which is labeled Carrier Section. It is the purpose of this portion of the transmitter to generate the radio wave which serves as the carrier. Technically, this radio wave is a radio frequency wave, and it is usually abbreviated RF wave, or RF signal. The carrier (RF signal) and the amplified audio signal are both applied to the modulated amplifier. This portion of the transmitter combines the audio signal and the RF signal. The result is that the RF signal carries the audio signal "piggy back." This is why the RF signal is called the "carrier." The carrier is assigned to a definite frequency, or place, on your radio dial by the Federal Communications Commission. For example, WLW is assigned to a frequency of 700 kilocycles, or 70 on the dial of your radio.

Another technician is on duty at the transmitter, and it is his job to see that the transmitter is operating properly. He also records the readings of the many meters of the transmitter at regular intervals. The transmitter technician is shown recording the readings of the transmitter meters in Figure 14. This is done for two reasons. In the first place, a record of the meter readings is required by the Federal Communications Commission. Second, a close check of the meters can, in a great majority of cases, indicate that certain troubles are developing. For example, it can indicate that a particular tube is about to "burn out." Then the defective part, tube, or whatever it may be, can be replaced during one of the regular "off the air" periods, rather than cause a shutdown during the time when the station is supposed to be on the air.

Now that the audio signal has been combined with the RF signal, the combined signal must be "broadcast" in all directions to the radio receivers in the homes of the listeners. To do this the modulated carrier, which is the name applied to the output signal from the modulated amplifier, is carried by means of wires from the transmitter to the transmitting antenna. The transmitting antenna is usually a tall, vertical steel tower. When the modulated carrier flows into this antenna, it produces radio waves which spread out in all directions. (In certain applications, such as a radio beacon, the radio waves are focused by special types of antennas into narrow "beams.") The radio waves travel through space at the speed of light, which is 186,000 miles per second. The radio waves carry the audio signal through space.

In our short trip through a radio station we have seen how sound waves are changed into audio signals, how these audio signals are combined with the carrier, and how this combined signal is broadcast. Now let us see how a radio receiver handles the problem of changing the radio waves back into sound waves.

The Radio Receiver

As the radio waves travel through space they hit radio receiver antennas. These antennas might be located outside, as they were for many years, or might be built into the cabinets of the radio receivers. As the radio waves hit an antenna, they cause a weak Radio Frequency signal to be set up in the antenna. This weak Radio Frequency signal set up in the antenna of the receiver is exactly the same as the modulated carrier signal at the transmitter except it is much weaker. It is probably less than one-millionth as strong as the modulated carrier signal at the transmitting antenna. The receiving antenna conducts the weak RF signals to the RF amplifier of the receiver as shown in the simple block diagram of Figure 15. There are a number of different methods used in receivers to handle this weak RF signal and change it into sound waves, and Figure 15 illustrates one method.

The RF amplifier in the receiver does two things. First, it tunes in the desired station and tunes out all of the undesired ones. It should be remembered that there are thousands of stations broadcasting at the same time, and the radio waves from most of these transmitters are hitting the receiving antenna and setting up RF signals in it. An unintelligible jumble would result if all of these were amplified and were heard in the loudspeaker at once. The RF amplifier selects the one station to which it is tuned and rejects the others. (The tuning process is one of the most interesting things in radio theory, and will be taken up in detail later in the training program.) Second, it amplifies the weak signal from the antenna so that it will be strong enough to use. After the RF signal has been amplified, it is passed along to a demodulator stage, commonly called a detector, which reclaims the audio signal from the RF carrier which brought it that far.

The action of the demodulator stage in the receiver is just the opposite of that of the modulated amplifier in the transmitter. The demodulator, or detector, separates the audio signal from the RF signal. The RF signal is discarded, since its only purpose was to carry the audio signal. The audio signal is then conducted into an audio amplifier stage, which builds it up to a sufficient strength for operation of a loudspeaker. When the audio signal flows through the windings of the loudspeaker, it causes the paper cone-shaped diaphragm of the loudspeaker to vibrate in exact step with the vibration of the diaphragm of the microphone in the broadcasting studio. This vibrating cone produces sound waves in the air which travel to the ears of the listeners. Thus, a perfect reproduction of the music or voices in the broadcasting studio is heard by the listeners. In other words, the listener hears the same sound he would hear if he were present in the radio studio.

Summary of the Radio System

To summarize briefly the foregoing actions: At the studio we have taken sound waves in air, changed them to audio signals, amplified them, combined them with a carrier, and broadcast radio waves having the characteristics of the original sound waves. In the receiver we have "picked up" this weak modulated RF signal, amplified it, removed the audio signal, amplified this audio signal and passed it through a loudspeaker which again produces sound waves. Since radio waves travel at 186,000 miles per second, all of this happens in a split second. If a listener is sitting near his radio, he will actually hear the program a fraction of a second before a listener in the rear of the broadcasting studio would, because sound waves in the studio will travel only 1,089 feet per second.

The Television System

Since the first crude television picture was shown in 1927, television has captured the fancy of the public in a manner undreamed of by any other technical achievement. However, television--which is a transmission of both pictures and sound without the aid of wires--took almost 20 years of intensive research to develop to the point where the quality of the transmission was good enough, and the cost low enough, to insure its popularity with the general public. Thus, it was not until 1946 that commercial television became a reality. Even after this time technical advances were being made, and the Federal Communications Commission placed a ban on new station construction after 108 TV stations had been placed on the air. This ban was lifted in 1952, and since then TV transmitting stations and their associated antennas, as pictured in Figure 16, have been springing up so rapidly that almost every community large enough to appear on a map is now able to receive TV from one or more transmitting stations. The development of color television is adding to the impact of television. Even the Army finds application for television, as shown in Figure 17.

Most television programs originate in specially constructed TV studios (See Figures 18 and 19). As TV consists of the transmission of both pictures and sound, there are two separate operations taking place at the same time. The problems of handling the sound portion of the program are quite similar to those of radio, except the microphone is usually suspended above the performers from a microphone boom, as may be seen in Figure 19. Television cameras are used to "pick up" the picture portion of the program. Cameras and cameramen can also be observed in Figure 19. A closeup of a television camera and cameraman is given in Figure 20, a television camera in operation in the TV Studio of United Electronics is illustrated in Figure 21, and Figure 22 shows a closeup view of a TV camera with the top open.

Now that we have had a picture of the TV studio and the equipment located in it, let us see how it is possible for the television system to "pick up" a scene in the television studio, and reproduce this scene on the screens of thousands, or even millions, of TV receivers.

Probably the first thing which should be emphasized is the fact that there is no film in a TV studio camera. Instead, the TV camera contains a camera pickup tube, or picture tube, as it is often called. Located on the front of the camera is a lens turret, which normally mounts four lenses, as may be seen in Figures 20 and 21. By means of a handle on the back of the camera (See Figure 22), the cameraman can choose whichever lens he desires for use at a particular time. Through the action of the lens the scene being televised is focused on a sensitive plate in the picture tube, as illustrated in Figure 23.

Stated very briefly, then, the TV camera changes this optical image into electrical signals somewhat similar to the audio signals produced by a microphone. These signals are sent to the transmitter, where they are combined with a carrier. The combined signal then goes to the transmitting antenna for broadcasting. TV receiver antennas, some of which are many miles away from the transmitter, pick up the weak TV signals. After much signal amplification, the scene is reproduced on the screen of the TV set, which, as Figure 24 illustrates, is actually the "front" part of the picture tube.

The manner in which the scene focused on the sensitive plate of the television camera pickup tube is changed into an electrical signal, and how this electrical signal is then changed back into a reproduction of the scene on the screen of the television receiver, is, indeed, an interesting process.

How a Picture Is Reproduced

When one watches the screen of a television receiver, he thinks he sees a "moving picture" being presented on the screen before his eyes. However, this is actually an optical illusion. No means has ever been developed for transmitting an entire picture at one time so that the television receivers can reproduce an entire picture at one instant. All workable methods of TV consist of breaking the picture up into many thousands of parts, transmitting each of these parts one after another, and then putting these parts together again properly at the receiver to obtain the complete picture. The fact that the picture must be broken down into parts for transmission and the parts then put back together at the receiver accounts mainly for the fact that television transmission is complex as compared to radio or sound broadcasting.

Perhaps it would be of interest to point out that almost all means of reproducing pictures employ processes of breaking the picture down into small areas of light and dark. If you have a magnifying glass, or can borrow one, look at a newspaper photograph under this glass. You will discover that it is made up of small dots of ink--in other words, the original picture is broken down into the small dots of light and dark to reproduce it on the newsprint. If you were to use a good magnifying glass to examine a photograph in a magazine, you would discover that it, too, is made up of many small dots, but that the dots are smaller and closer together than in the case of the newspaper reproduction. As a result, you can see more of the fine details in the magazine picture than in the newspaper picture. Even an ordinary photograph, if you could examine it under a very powerful magnifying glass or a microscope, would be found to consist of many dots (in this case they are dots of a silver compound) which are very small and very close together. A good photograph will contain even a greater amount of fine detail than a magazine reproduction. From this it can be understood that it is possible to break up any picture into a large number of small areas or dots of light and dark, and that the smaller these areas are, and the closer they are together, the more detail will be shown in the picture.

As mentioned, television also breaks up the picture into a large number of small areas of light and dark. However, there is one major difference between the reproduction of a television scene and the reproduction of a printed picture. When a person looks at a picture in a newspaper he sees all of the picture at once, because all of the small areas of light and dark are there for him to look at as long as he desires. In television, the picture is not reproduced all at once. Instead, each successive area of light and dark is reproduced, one after another, at such a rapid rate that the eye is tricked into believing it is seeing the entire picture at once.

After the eye responds to a change in light intensity, it retains the impression for approximately one-tenth of a second. Thus, if all of the small areas of light and dark forming the television picture are assembled on the TV screen at a rapid enough rate (in less than one-tenth of a second), this characteristic of the eye tricks the observer into thinking he is seeing the entire picture before him. Another thing which adds to this effect is the nature of the screen of the picture tube itself. The fluorescent material used for the screen is such that any spot which is caused to glow will continue to glow for a fraction of a second afterward.

The Television Picture

In the television system, the image to be transmitted is first broken up into narrow strips or lines, and these lines are, in turn, broken up into dots of light and dark. Figure 25 illustrates the manner in which a picture may be broken up into lines and then reproduced. The picture at the left shows the original scene, and at the right it can be seen broken up into the individual strips, or lines. If we were to reassemble all of the individual lines at the right, by moving them close together, they would form the original picture.

The process in which a scene is divided into individual lines, and these lines reassembled at the receiver to form a reproduction of the picture, is called scanning.

Scanning can be explained very easily by the following example. Assume that on a very dark night, a man desires to read a large sign on a wall. The only means of illumination he has is a flashlight which produces a narrow beam of light. To read the sign he would, naturally, first direct the beam at the upper left corner of the sign, and then move it across the top portion of the sign. He would then lower it slightly and again trace across the sign, this time tracing out the second line of the sign. This process would continue until the entire sign had been observed. The flashlight illuminates only a small spot, but if it is moved rapidly, a whole strip or line appears visible. If it were possible to thus scan the entire sign in less than a tenth of a second, the eye would be tricked into "seeing the whole sign at once."

In the television system, the scene to be televised is focused on the pickup tube in the camera, and the reproduced scene appears on the screen of the picture tube in the receiver. The scanning is done entirely through the use of electricity. In the camera tube, a pencil-point-thin beam of electricity moves from the left edge of the top line, or strip (See Figure 25) progressively to the right edge of this line. Thus the beam of electricity corresponds to the flashlight beam in our example. As the beam scans across the picture, it "senses" whether it is hitting upon a white, black, or gray area. In the picture tube of the TV receiver, another pencil-point-thin beam of electricity traces a strip progressively across the top edge of the TV screen. It reproduces a white area on the receiver screen each time the beam in the camera tube is striking a white area. Similarly, a black area is reproduced on the TV receiver screen when the beam in the camera tube is striking a black area, and a gray area is reproduced when the beam in the camera is striking a gray area. This ability of the beam of electricity in the camera tube to "sense" whether it is hitting upon a white, black, or gray area makes it possible for each line of the picture to be broken up into the small areas of white, black, and gray, just as was mentioned regarding a newspaper picture.

After the first line has been scanned, the scanning beam in the camera and the one in the receiver picture tube move rapidly back to the left edges of their screens, and down slightly. They then scan another line slightly lower on the picture than the preceding line. This process is repeated, line by line, until the entire picture has been scanned. Thus the areas of light and dark forming each line of the screen appearing before the camera are reproduced on the screen of the receiver. The entire picture is reproduced on the receiver screen in such a brief period of time that the eye of the viewer is tricked into seeing the entire picture at once. This process is repeated over and over again.

In the actual television system the scene to be reproduced is broken into many more lines than those shown in the demonstration scene of Figure 25. This makes it possible for the TV system to reproduce the fine details in the picture. Just as soon as the scene has been completely scanned, the scanning process starts over again. If the people in the scene have moved, they will appear at slightly different locations in the successive scenes, which follow each other at intervals of 1/30 second, and thus the illusion of motion is established.

The scanning process is actually the "heart" of television. It makes it possible for the television system to break down its "picture" into a series of dots of light and dark, just as the picture in the printing process is composed of dots of light and dark. After this has been done at the studio, and the "picture signal" formed in the process, this "picture signal" is then combined with a "carrier" signal for transmission in a manner quite similar to the arrangement explained for radio broadcasting. The TV receiver reverses the process by taking the "picture" signal away from the "carrier." It applies the "picture" signal to the picture tube, where the scanning process in the receiver reassembles the complete picture. This, in a nutshell, is the fascinating, the challenging process of television.

Looking Ahead

This assignment gives you a simple, over-all picture of the radio system and the television system. Of course, this picture is not complete, but merely serves as an introduction to the electronics field, and gives you a "speaking knowledge" of the entire system. Each fundamental electronic and TV unit will be discussed in detail later in the training program. To illustrate this, refer again to Figure 10. This photo shows an announcer speaking into a microphone. In this assignment, you were told that the microphone is similar to the mouthpiece in a telephone, and that it changes sound waves into electrical waves called audio signals. This is true, but it is not the complete story of a microphone. Later in the training program, one entire assignment will give a complete explanation of the various types of microphones and the proper use of each type. You will learn, then, that there are many different types of microphones, each using a slightly different principle, to do the same job--changing sound waves into audio signals. Similarly, you will look at audio signals more closely, so that you will learn all you need to know about them.

As you go along in the training program, you will see what we mean when we say the entire training advances in a step-by-step process. For example, in the next assignment you will learn to recognize the various electronic parts, and find out, in a basic manner, what each does. In the following assignments you will learn how to "read" radio and electronic wiring diagrams, or circuit diagrams, as they are called, and how to draw them yourself.

A little further in the training you will be given the latest information on just what electricity is, and its relationship to magnetism. You will then be shown how both of these very interesting natural forces are used in electronics and television. Each of these basic things you learn will add a step to the stairway you are building and climbing toward becoming a thoroughly qualified electronics technician. The remaining assignments will be just as interesting as the first, and, equally important, you will keep learning more and more from each one. Your knowledge will grow by leaps and bounds as you master the fundamental laws and facts given in each assignment.

A thorough training in electronics is worth every bit of the time and effort you give to obtain it. You are qualifying yourself for a field that is "wide open" in opportunities--exceptional opportunities that are available only to those who "know what they are doing" in electronics. Each time you tackle a new idea <u>and master it</u>, you advance your skill and experience in this field.

Many thousands of hours of thought, preparation, and revision have gone into this training program, so that each subject will be presented as thoroughly as possible and as simply as possible. Because of our constant touch with the industry, we are able to include in the training all of those things which you need to know to meet the industry's requirements and to become a thoroughly qualified technician. Similarly, any information which has lost its value to the over-all electronics field has been eliminated. In this manner, the training program will provide you with the information you need, without holding up your progress while you are studying unnecessary material.

In this training program, you will supply the ambition, but you're working directly with an instructor. He is right behind you, ready to give you help whenever you need it. To learn new material it is, of course, necessary for you to do the studying and thinking, but your instructor is eager to help you. He'll be glad to explain anything in a different way whenever you desire. You, yourself, know whether or not you understand an explanation. Before going from one part of an assignment to the next, make sure that you do understand.

We know that you will do your very best to master each new idea yourself. However, we do not expect you to understand everything without some help. At some point in the training you may run across something that just doesn't seem to make sense to you. Be sure to remember, when and if this happens, that your instructor is eager and prepared to give you personal instruction and the special explanations you need. Just tell him exactly what point you do not understand. Use the Consultation Service Blank which has been supplied for this purpose. When your instructor returns your answer to you, he'll send you another Consultation Service Blank for your future use. Do not hesitate to use the Consultation Service whenever you feel the necessity. This is a fundamental part of the over-all training program. We don't want you to have a single technical question left unanswered as you progress through the training.

After you have finished your work on this assignment, send in your answers to the test questions for grading. Then start your work on Assignment No. 2 as soon as possible, without waiting for your graded answers for Assignment No. 1 to be returned to you. This will make it possible for you to advance through the training program without delays.

Again--congratulations on your forethought in deciding to enter the electronics field--lots of luck--we're with you!

Assignment 1

TEST QUESTIONS

Be sure to number your Answer Sheet ASSIGNMENT 1. Place your Name and Associate Number on every Answer Sheet. Send in your answers to this assignment as soon as you have finished with it. This will give you the greatest possible benefit from personal grading services.

1. Which travels faster, a sound wave or a radio wave?

2. List at least two uses of electronics. (Do not include radio, television, or radar.)

3. What is the purpose of a microphone?

4. Are microphones used in television?

5. Name at least two radio services other than standard radio broadcasting.

6. In a television system, is the entire picture transmitted at one time, or is the picture "broken up" into parts and these parts transmitted?

7. What does the control operator in the control room of a radio broadcasting station do when he is "riding the gain"?

8. The RF signal in a radio transmitter is called the carrier. Why?

9. What two things does the RF amplifier in a radio receiver do?

10. In our example, the man "scanning" the sign on the wall used the beam of light from a flashlight to do this scanning. What kind of beam is used in scanning the image in a television camera?

HOW THE CAMERA TUBE WORKS

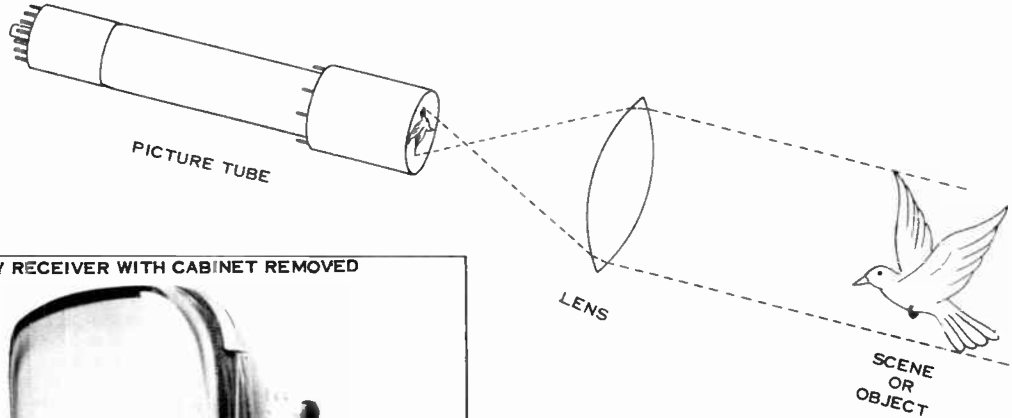


FIGURE 23

This sketch illustrates, simply, how the image is handled as it passes through the lens of a television camera.

TV RECEIVER WITH CABINET REMOVED

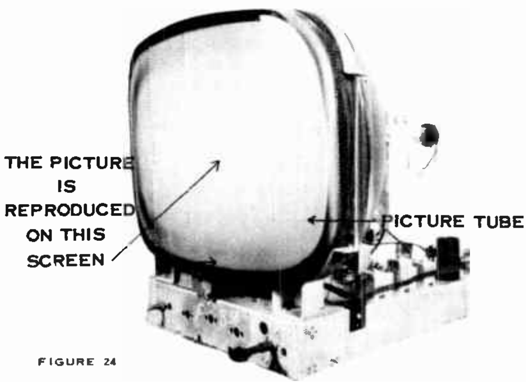


FIGURE 24

The picture tube in a TV set is very large, and the TV screen is formed by the "front" of the tube.

BREAKING UP A PICTURE INTO LINES

FIGURE 25 (COURTESY CBS-TV)

The figure at the right shows how the scene at the left (Sylvania's Roxanne) may be broken up into strips, or lines. In your mind's eye move the strips together, and you will be able to visualize how a TV picture may be broken into lines and then reassembled to form a complete picture.

ULTRA—MODERN BROADCASTING STATION

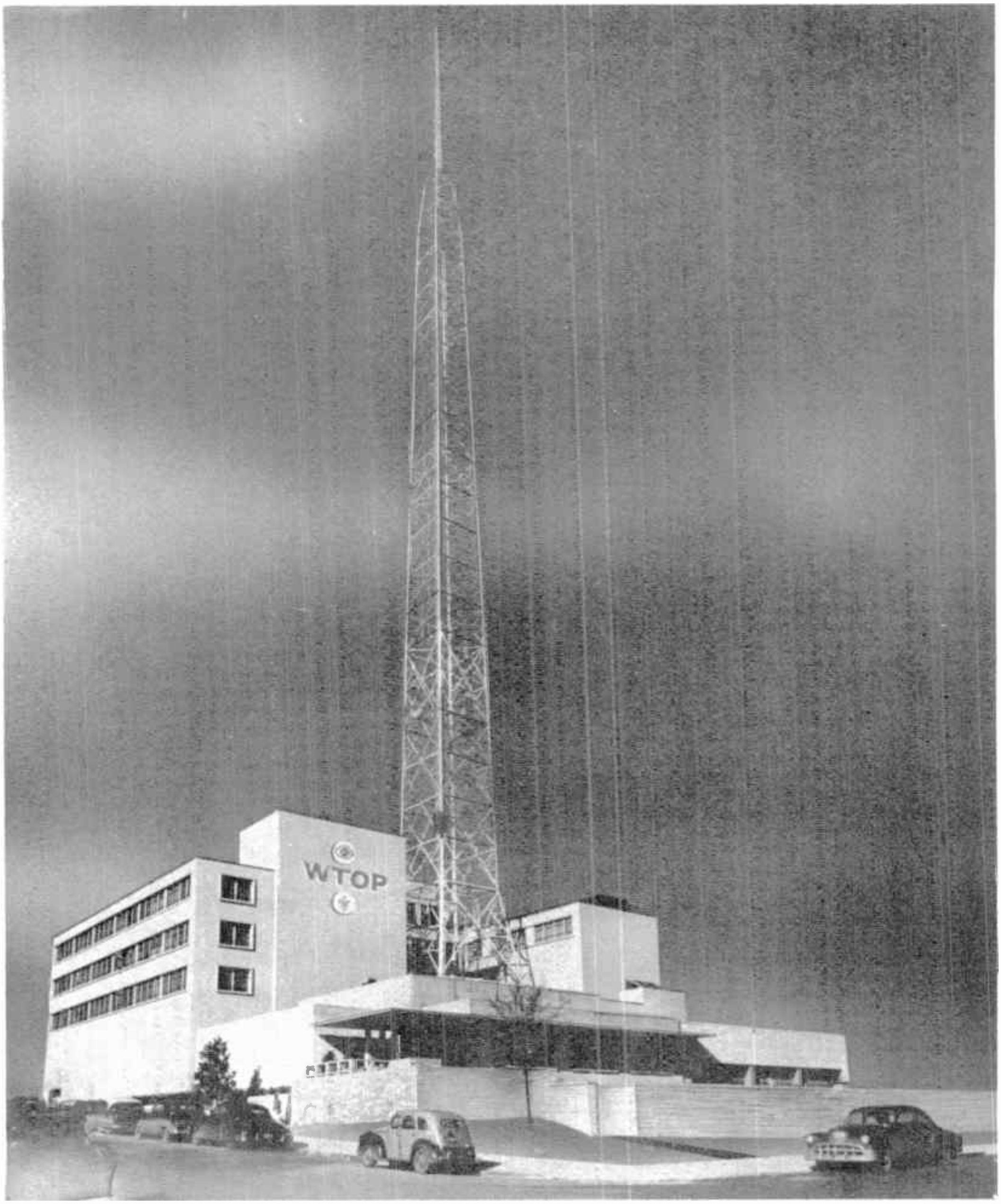


FIGURE 1 (COURTESY WTOP, WASHINGTON, D. C.)

This specially designed building houses a Standard Broadcast Radio Station, an FM Broadcast Station, and a TV station.

AIRCRAFT RADIO

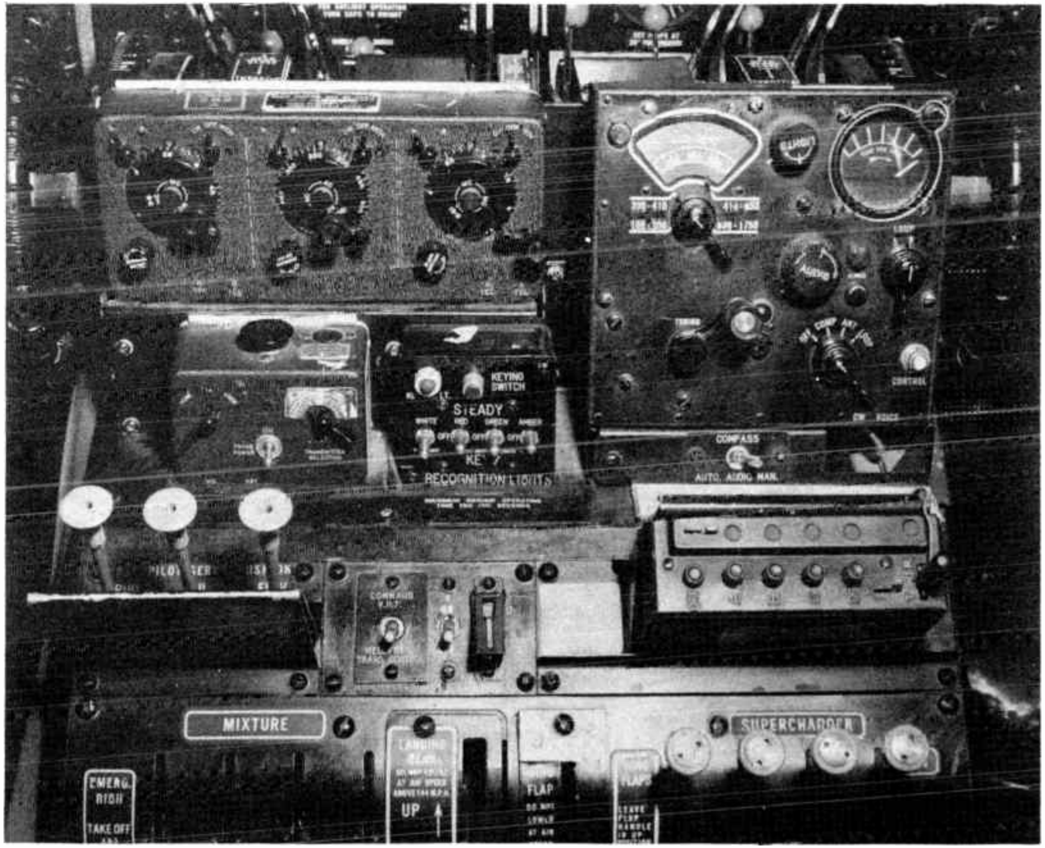


FIGURE 2 (COURTESY PAN AMERICAN WORLD AIRWAYS SYSTEM)

This is just a portion of the radio and electronic equipment carried by modern airliners.

NAVIGATIONAL RADAR

FIGURE 3

(COURTESY SPERRY GYROSCOPE CO.)

This piece of Radar equipment, aboard the Dutch Lines' NIEUW AMSTERDAM, is typical of the Radar installation on ocean-going vessels.

TEST TECHNICIAN AT WORK

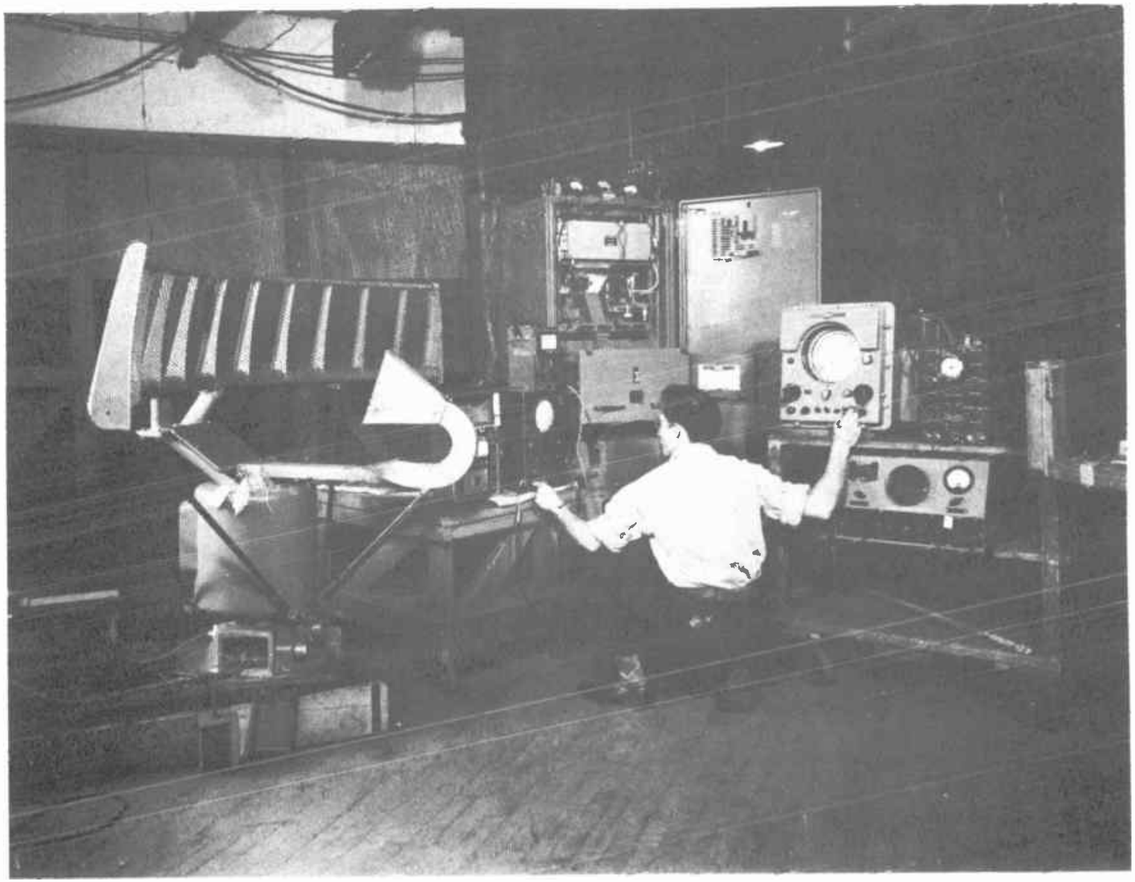


FIGURE 4

(COURTESY RAYTHEON MFG. CO.)

This Radar system is being "put through its paces" by a technician prior to its installation on shipboard.

WORKING ON AN ELECTRONIC BRAIN

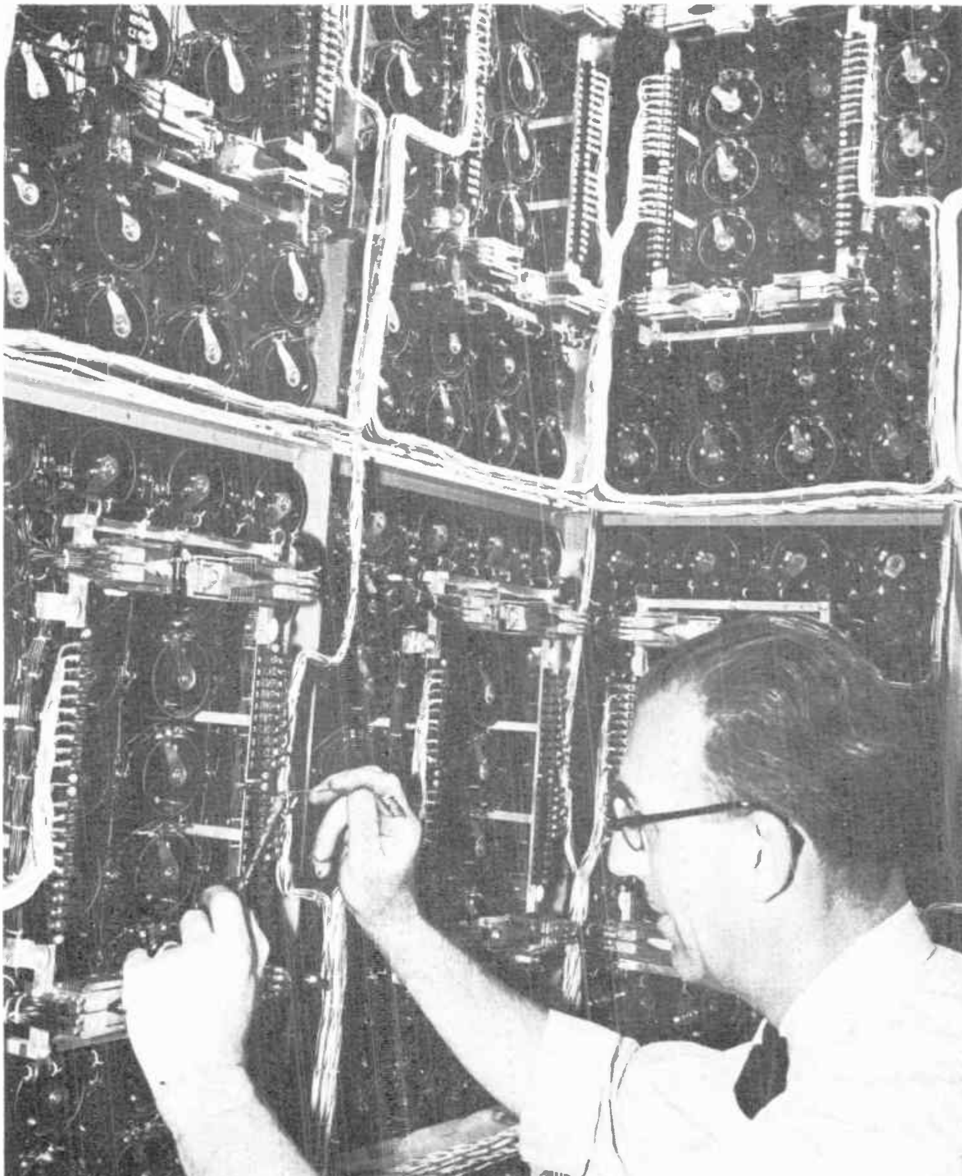


FIGURE 5 (COURTESY GENERAL ELECTRIC CO.)

This test technician is making a wiring change on an electronic brain. This particular "brain" was designed by GE for the American Gas and Electric System, and simulates, mathematically, one of the nation's largest electric power networks. Its use is expected to save AGE about $100,000 yearly.

ONE OF NBC'S TV STUDIOS

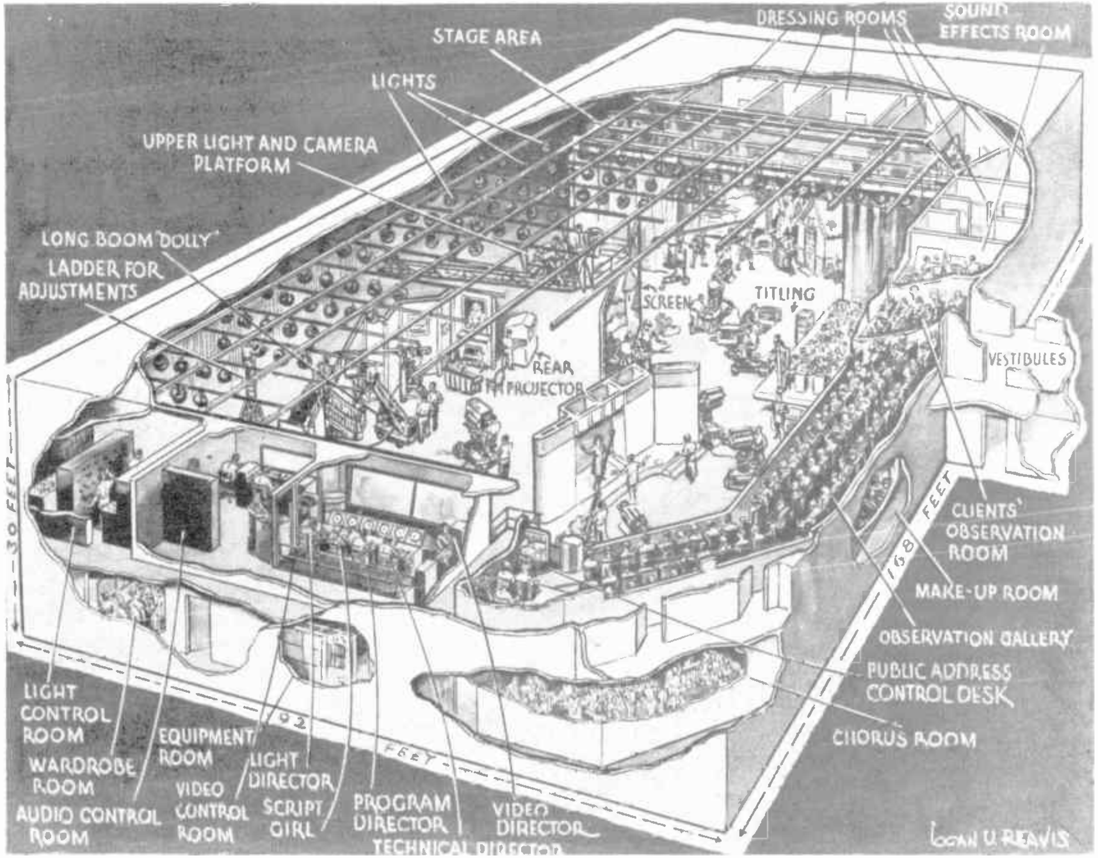


FIGURE 6

(COURTESY NBC-

The "cut away view" shows one of NBC's studios in New York City. Note the array of equipment personnel.

CBS TELEVISION CITY

FIGURE 7

(COURTESY CBS-TV)

This photo shows Lucille Ball, star of "I LOVE LUCY," the Mayor of Los Angeles, and the vice president of CBS-TV throwing the master switch which inaugurated nightly illumination of CBS TELEVISION CITY while it was under construction.

WHERE THE SOUND COMES FROM

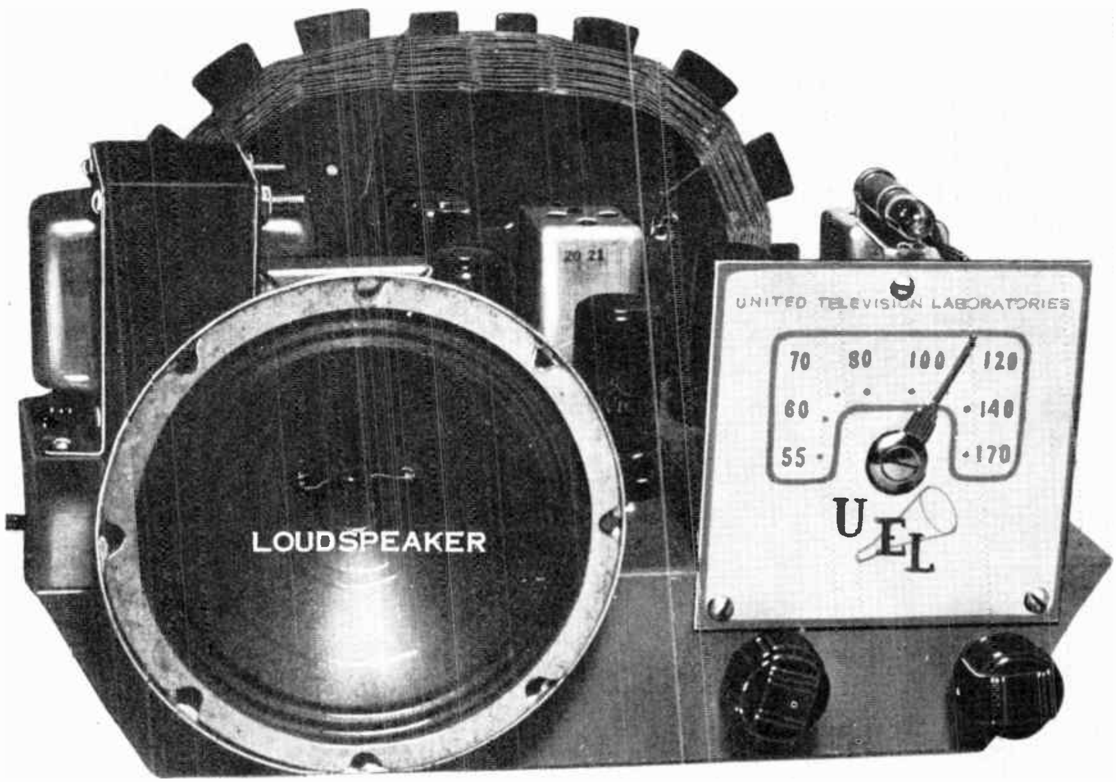


FIGURE 8

The vibrating cone of the loudspeaker sets up sound waves in the air.

FIGURE 18

(COURTESY KROD-TV, EL PASO, TEXAS)

This beautiful new building houses the studios of KROD-TV in El Paso, Texas.

ARMY TV EQUIPMENT

FIGURE 17

(COURTESY U. S. ARMY SIGNAL CORPS)

This Signal Corps remote TV system is one of the most complete TV stations ever mounted on wheels.

ANOTHER TV ANTENNA

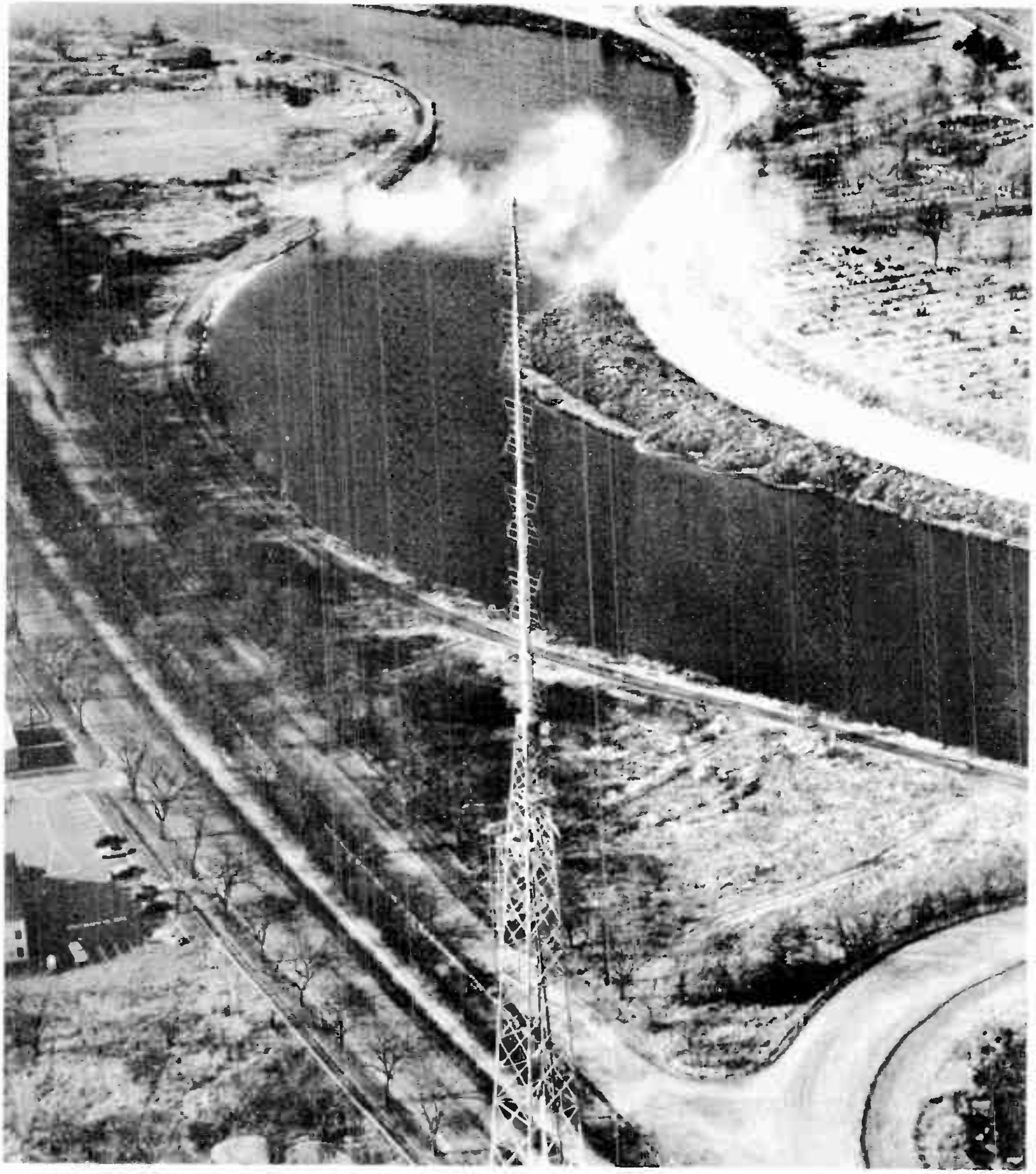


FIGURE 16 (COURTESY GENERAL ELECTRIC CO.)

This particular antenna, mounted atop a 573-foot tower, radiates WBZ-TV's signal over a radius of approximately 100 miles from Boston, Mass. Many similar structures are dotting the skyline from coast to coast.

BLOCK DIAGRAM OF RADIO BROADCASTING STATION

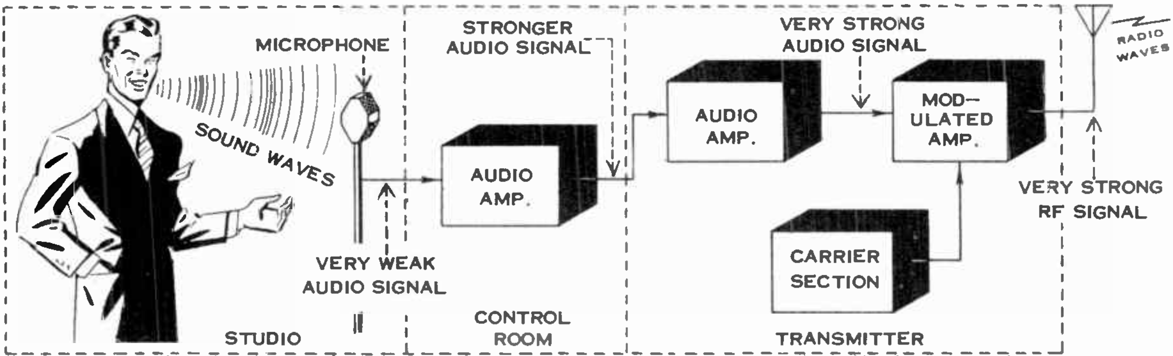


FIGURE 13 This simple block diagram illustrates the operation of a radio broadcasting system.

LOGGING THE DIALS

(COURTESY WAAM, BALTIMORE, MARYLAND)

Periodic reading of the equipment meters, logging the readings, and making constant comparisons keep the station's equipment functioning full time at maximum efficiency.

FIGURE 14

BLOCK DIAGRAM OF RADIO RECEIVER

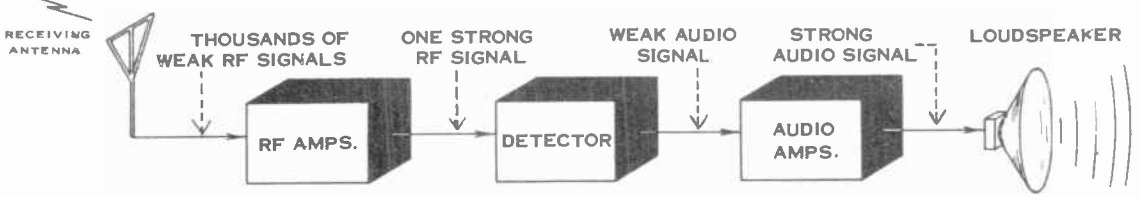


FIGURE 15

This simple block diagram traces the path of a radio signal through a receiver, to emerge from the loudspeaker as sound waves.

CONTROL CONSOLE

FIGURE 12 (COURTESY CANADIAN BROADCASTING CORP.)

The technician at the control console regulates the volume of the audio signals. He also handles the switching from the various microphones, the transcription turntables, and from the network.

HOW SOUND TRAVELS

FIGURE 9

The sound waves travel outward from the speaker and strike the eardrums of listeners to produce the sensation of sound.

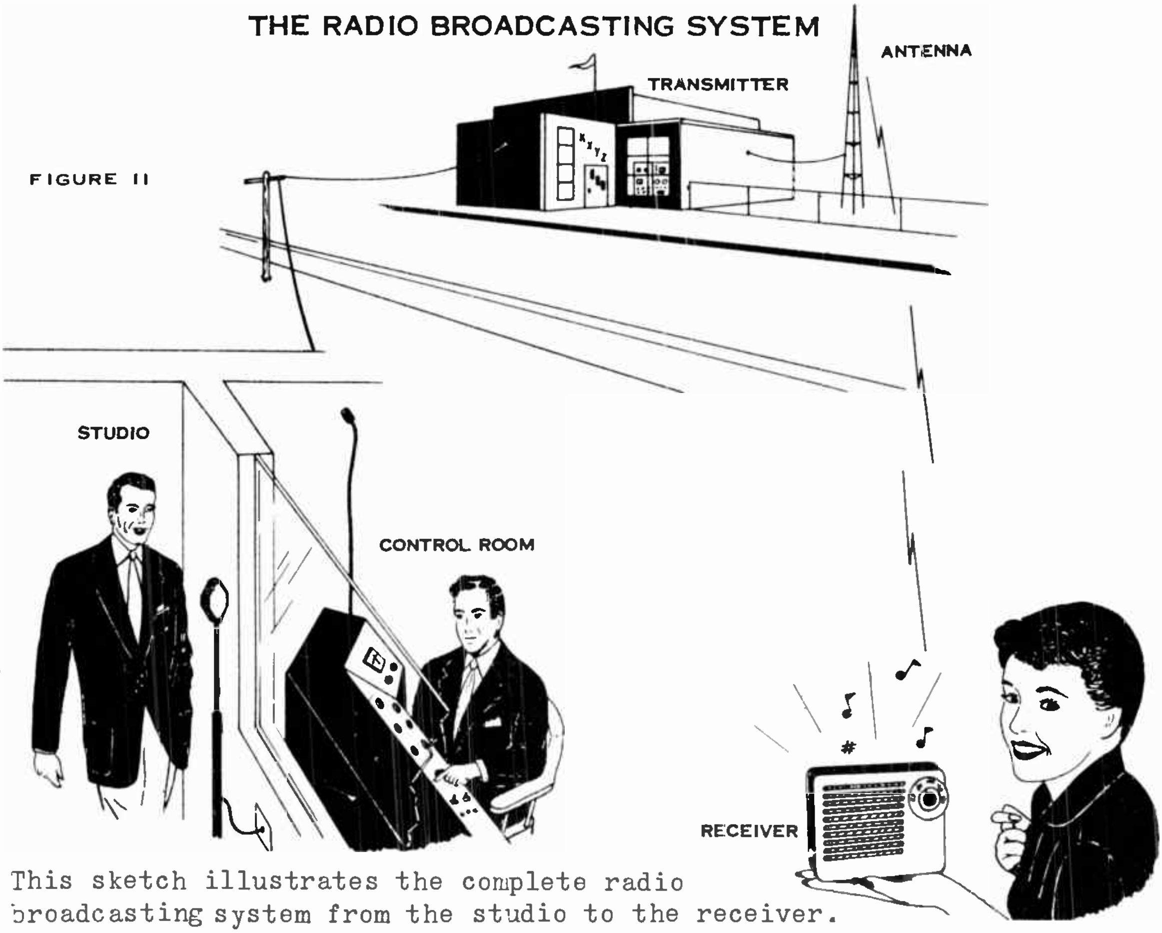
THE MIKE IN THE RADIO STATION

FIGURE 10 (COURTESY THE CHRISTOPHERS)

As the newscaster speaks, the sound waves set up by his vocal cords travel to the microphone which converts them into audio signals.

THE RADIO BROADCASTING SYSTEM

FIGURE 11



This sketch illustrates the complete radio broadcasting system from the studio to the receiver.

TV STUDIO SCENE

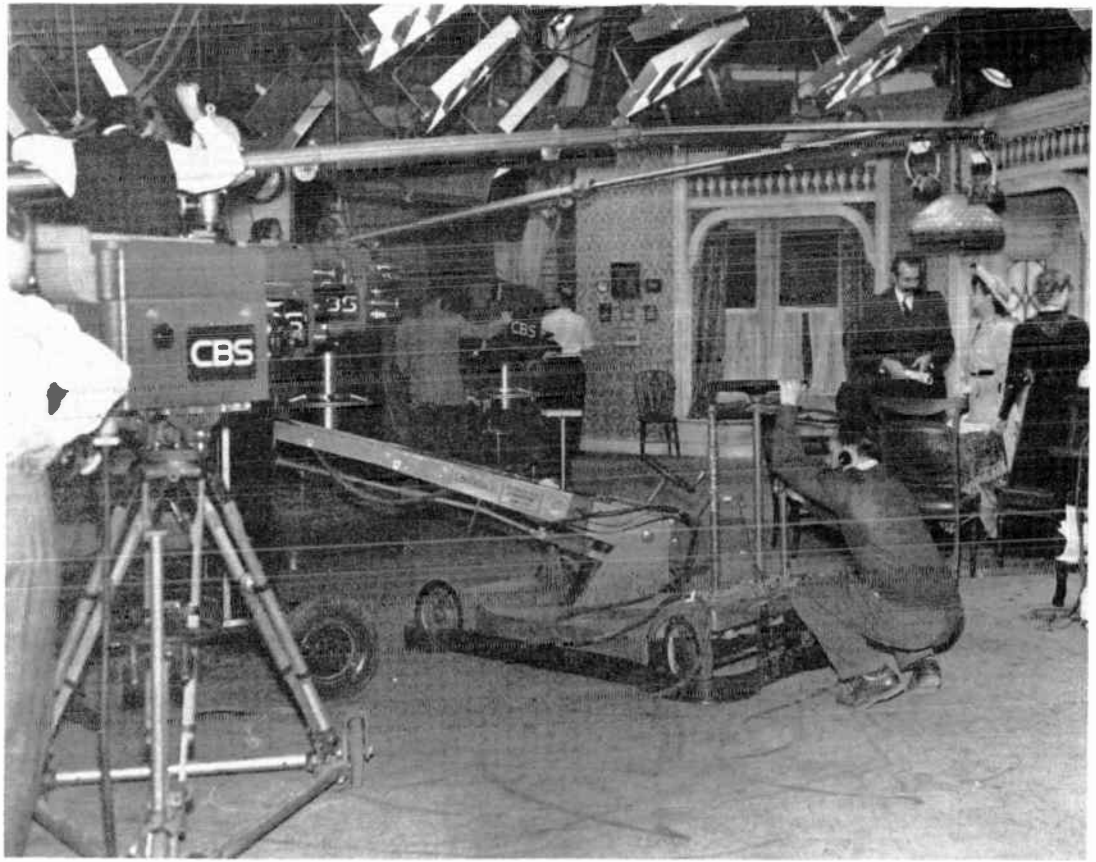


FIGURE 19

(COURTESY CBS-TV)

This on-the-air shot shows a program being televised. Note the lighting equipment, the "boom" microphones suspended above the heads of the performers, and the TV cameras and cammermen. (two cameras are partly hidden from view, behind the first camera.) An assistant cameraman and other production personnel may also be seen.

INSIDE VIEW

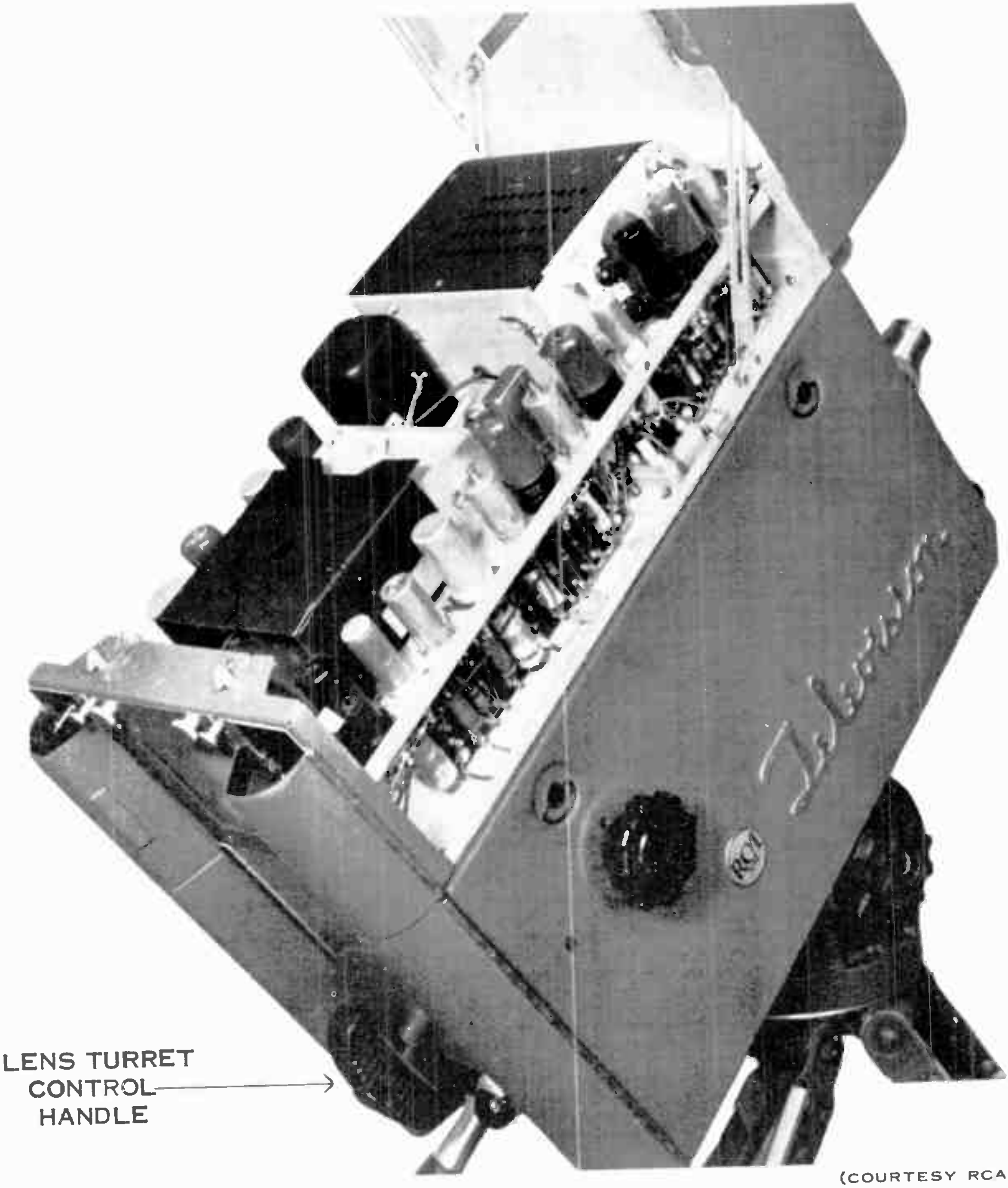


FIGURE 22

When the top of a TV camera is opened, the tubes and other electronic parts are exposed, so that the TV technician can make adjustments or repairs.

UEL ASSOCIATES IN ACTION

FIGURE 21

Here are shown four United Electronics Associates, operating one of the TV cameras and a boom microphone in one corner of the spacious, fully equipped, air-conditioned studios in the UEL training building. To the left of the Associates may be observed lighting equipment, studio monitor, scenic backdrop, etc., and behind the Associates are the soundproof windows to the control room.

A TV CAMERAMAN IN ACTION

FIGURE 20 (COURTESY CANADIAN BROADCASTING CORP.)

This close-up shot shows a cameraman in action. The four lenses on the front of the camera are mounted on a " turret," and the turret may be rotated by means of a handle projecting from the rear of the camera (See Figure 22), to place the desired lens in front of the camera pickup tube.

Electronics

Radio

Television

Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

ELECTRONICS PARTS IN A RADIO RECEIVER

ASSIGNMENT 2

ASSIGNMENT 2

THE ELECTRONICS PARTS IN A RADIO RECEIVER

Industrial electronic equipment and radio and television receivers have much in common. Although they may be doing a different job - the industrial electronic equipment may be controlling a production process, whereas a radio receiver is merely reproducing entertainment - these units operate on the same basic principles. They also use the same basic parts - coils, condensers, resistors, tubes or transistors, etc. At this time we are going to look at some of the parts, to become familiar with them and how they are used in actual equipment.

In Assignment 1 we looked at the basic principles of the transmitter and receiver of the radio and television broadcasting system. Let us now continue our study of electronics in a practical way, by using a small, table-model receiver - such as can be found in nearly every home, or can be borrowed from friends - as our first practical project.

It is suggested that you read through this entire assignment at least once, to get a mental picture of just what the assignment covers. Then, go through it paragraph by paragraph, with the actual radio before you. For the present, we will *look* at the various component parts and examine the connections. This will give us a world of knowledge about the parts used in all types of electronic equipment. If we understand the directions and follow them carefully - if we do not make any changes or adjustments - the radio will remain in good condition. In fact, the radio will be in better operating condition when we finish than it was when we started.

The choice of a radio to use in this assignment is not at all critical - any will do, from the smallest to the largest. However, a small table radio, somewhat similar to that in Figure 1, is easier to handle, and you will have less chance to become confused by connections to a phonograph, extra loudspeakers, etc.

A Word of Caution

A word of caution is in order before we begin. On some of the parts in the radio - for example, on the tuning condenser and the I-F transformers with which we will become familiar presently - there may be a number of screws or nuts, which may seem to need tightening. However, none of these should be turned or tightened under any circumstances. These screws or nuts may be for the purpose of adjusting critical circuits in the receiver, rather than to just "hold things in place." If you were to move any one of these as much as a quarter of a turn, one way or the other, it might make the radio completely inoperative.

Rough-Testing the Receiver

Having selected our radio, we should first of all "rough-test" it. This simply means to check to see if the radio is in proper operating condition. If it is an electric model, check to see if the line cord is in good condition, the insulation is not frayed or worn through, the plug is not broken, and of course, the plug must be securely plugged into an outlet of the proper voltage and current. If it is a battery model, we should see that the batteries are good and that they are connected properly. Next, check to see that the antenna and ground wires - if used - are in good condition and properly connected. Most small table-model radios have a built-in antenna with provisions for adding an outside antenna, if necessary. Few modern table-model radios use an outside ground wire and unless there is a connection clearly marked "ground" on the radio, never use one. If a ground wire is connected to this newer type receiver, or if the metal chassis or base of the receiver comes in contact with some metal such as a waterpipe, the house fuses may be blown and the radio damaged.

The next step in our rough-test examination should be to turn the radio on and by operating the various knobs or controls, see what effect they have on the operation of the radio. Having assured ourselves that the radio is operating satisfactorily and that we know what each of the knobs does to the operation of the radio, let us turn it off again and disconnect the antenna and ground wires (if used) and remove the a-c plug from its socket. Begin at once to practice the correct way for doing each job. For example, to remove the plug from the socket, pull on the plug itself and not on the wire. In removing the antenna and ground wires, tag them or write down their color scheme to insure being able to reconnect them properly, with the least amount of trouble and effort. An expert electronics technician plans his every step and goes through the operation first in his mind. Then, he follows through with the actual operation.

Removing the Knobs

Now let us carefully examine the radio we are using in this assignment and see what we can learn about it. For example, it probably has several knobs which must be removed if we want to take the radio chassis out of the cabinet. These knobs fit over a metal shaft which is a part of some component in the radio. Often the knob is held in place by a small metal "set screw". Looking at the side of the knob rather than the front, and rotating it, we may see a small opening and inside of this opening, the head of the screw. To remove this type of knob, loosen this screw with a small screwdriver and pull lightly on the knob. Of course, standard screws may be loosened by turning the screw to the left or counter-clockwise and tightened by turning the screw clockwise. Later on, when the knobs are replaced, the set screws should be tightened just enough to keep the knob from slipping on the shaft.

If the examination of the sides of the knob discloses no set screws, try pulling on the knob. On a great many modern radios the knobs are held in place on the shaft by a flat spring and may be removed by pulling on the knob. It may be necessary to pry it off with a small screw-driver if it fits very tightly, but care must be taken not to scratch the cabinet or break the knob. After you have removed the knob, notice how it fits on the shaft and plan to replace it in exactly the same way.

Removing the Chassis

Now we shall examine the entire radio cabinet, paying particular attention to the bottom and back in order to see how the chassis, or radio proper, is held in place. Probably several screws or bolts hold it in place and these will have their heads coming out the *bottom of* the cabinet. When all the necessary bolts have been removed, the chassis should slide out easily from the cabinet. Be careful not to damage the speaker and the dial assembly. If the speaker is not a part of the chassis and does not come out with the chassis be careful not to break or damage the wires leading to it. Sometimes these wires terminate in a plug which may be pulled out; sometimes they are connected by screws, which, when loosened, enable them to be removed. When removing them, be sure you are able to connect the proper wire to the proper point when you wish to replace it. Also, in removing the chassis from the cabinet, notice how everything fits together so that you can reassemble it quickly and easily.

If the receiver uses a speaker, which is mounted on the cabinet rather than on the chassis, let us remove it from the cabinet. We will notice that it is fastened to the cabinet by several bolts and nuts, the bolts most likely having ornamental heads without screwdriver slots.

A pair of pliers or a small wrench will enable us to remove the nuts from the back, but be careful not to allow the tool to slip and punch a hole through the paper speaker cone, thus ruining it. Notice how the bolts are made so that they do not slip or turn, even though we cannot hold them in place with a screwdriver.

If the radio chassis has not been removed from its cabinet for some time, the chances are it will be quite dusty. The next thing that should be done is to clean it up. This will serve two purposes. First, it will make the radio play better when we have finished, since dust and dirt are two major enemies of radio and electrical circuits. Second, by cleaning it thoroughly, we will notice more things about the radio. If this radio were one we were attempting to repair, we would be likely to notice things like burned resistors, condensers with the wax melting and dropping out of them, broken wires and poorly soldered joints, worn or chaffed insulation, etc. In cleaning the radio we should be careful not to disturb any of the adjustments or the wiring. The best way to clean it is with a small, soft brush and pipe cleaners and by blowing occasionally to remove dust deposits. A soft cloth also may be some help. We can remove the tubes *one at a time* being sure to replace them in their original sockets. Since the a-c plug is pulled out of the socket we need not worry about touching any of the parts and getting a shock. However, anytime the radio is turned on, common sense should tell us to be careful where we place our hands and fingers. All radios (except the smallest battery sets) employ voltages of 100 volts or more and under the proper conditions contact with this voltage could be very unpleasant. Even if this voltage is too low to be injurious, contact with it might cause us to jerk our hand away and break something or cut a finger.

Figure 2 shows a typical table model receiver chassis after it has been removed from its cabinet.

After the radio has been cleaned the control knobs should be replaced on their shafts. This is a precautionary operation, since the circuit wiring of some radio receivers is so arranged that it is possible for a person to be shocked if he touches the chassis or the control shafts at the same time he touches some grounded object, such as a radiator, if the power cord is plugged into a receptacle. If the speaker of the set has been disconnected from the chassis, let us now reconnect it in the original manner. Then connect the antenna and ground wires (if these were disconnected) and plug in the power cord. Now we may turn the radio on again. Notice that the radio will play without the cabinet but that the tone will not be as good. After this second operating test, pull the power cord out of its socket again.

What the Knobs Do

Now, let us see to what each knob connects and what this part does. First, notice that the knob which is used to tune in the desired radio station is connected, probably by a cord or cable, to both the dial mechanism and to a part made up of a number of fixed and movable plates. Notice that as we turn the knob the dial pointer moves and the movable plates are more or less enmeshed with the fixed plates. These two sets of plates should never touch each other or short together so we must be careful not to bend them. This part is known as a variable or tuning condenser. This condenser usually consists of two or three variable sections and we say that they are "ganged" together. Each section of the ganged tuning condenser consists of two parts, (1) a rotor and (2) a stator. The rotor of each section consists of the plates which rotate while the stator consists of those plates which remain stationary.

The stator and rotor plates of the ganged tuning condenser of a typical table model receiver are shown in Figure 3. It is the purpose of this tuning condenser, in conjunction with some coils, to select the desired station from the thousands which are on the air at any hour of the day or night.

Mounted on the top or the side of the ganged tuning condenser are small semi-variable condensers, called trimmer condensers. These condensers may be seen in Figure 3. These condensers usually consist of two small plates of metal separated by a sheet of mica. A slotted screw is used to adjust these condensers. At the present time, these adjusting screws should not be moved.

Examine carefully the dial cord assembly with its springs and pulleys. Quite frequently these dial cords break and the serviceman often has nothing more to go on than his experience and common sense in determining how to string a replacement cord. Figure 4 is a drawing of the dial cord arrangement of the receiver shown in Figure 2.

Also notice that the dial pointer will read "55" or beyond when the variable condenser is completely in mesh and somewhere between "150" and "170" when the variable condenser is completely out of mesh. The manufacturer's service instructions for this particular receiver more than likely tell exactly where to set the pointer when the condenser is completely out of mesh.

If the radio which is being examined has push-buttons for rapid tuning, try pressing them one at a time, and notice what happens in the receiver. There are two types of push-buttons in general use in modern receivers. One type of push-button rotates the tuning condenser when it is depressed. The other type of push-button operates a small switch when it is depressed.

The remainder of the knobs on the front of the receiver probably control parts which are mounted under the chassis, so let us turn the chassis over. Most receivers may be turned upside down without damage, when out of their cabinet, if we are careful with the loudspeaker and dial mechanism.

The knob which controls the volume of the radio rotates the shaft of a variable resistor known as a potentiometer. This unit will be discussed in detail later and a typical potentiometer is illustrated in Figure 5.

If the radio has a tone control, it probably consists of another potentiometer although in some sets it may be connected to a 2 or 3 position switch.

In most radios the on-off switch is a part of the volume control. This also will be discussed with potentiometers.

If the radio has one or more short-wave bands on it, the knob used to select the proper band will be fastened to the shaft of a switch similar to the one illustrated in Figure 6. Examine this switch carefully noting the number of sections or "decks" and the number of contacts on each deck. The one contact which is moved around and always connected to one of the other contacts is usually referred to as the "wipe". Watching it as you operate the switch, see if you can discover why.

Connected by wires to this switch are a number of coils. Even if the radio you are using does not have a short-wave band you will be able to see at least one coil mounted somewhere on the chassis, either above or below. This coil will consist of many turns of very fine wire wound around a cardboard or wood form. If your radio has a short-wave band, you will notice that some coils have fewer turns and larger wire on them than others. Some short wave coils may have only 6 or 8 turns of much heavier wire on the form. In some receivers, both the broadcast and the short-wave coils may be wound on the same form.

Parts Above the Chassis

Now let us return to the top of the chassis and observe the following parts with which we will now become familiar: Vacuum tubes and sockets, filter condensers, cans containing coils, and the power transformer.

The vacuum tubes may be of various types and they may have either glass or metal envelopes. Examine them closely, being careful not to break the glass loose from the bakelite or metal base. Let us remove them one at a time. They may be removed most easily with an upward motion while slightly rocking them from side to side. Notice how the tubes plug into the socket, paying particular attention to the spacing and arrangement of the prongs. The earlier types of tubes have from 4 to 7 prongs. These tubes have two prongs which are larger than the others so that they may be plugged in their sockets only one way. Later types of tubes have 8 equally spaced prongs and in the center have a keyed guide to prevent them from being plugged in incorrectly. Many newer receivers use new style, miniature tubes which are about the size of your finger and about 1½ inches tall. These tubes have unequal spacing of the prongs to prevent them being inserted in their sockets incorrectly. Notice the type numbers stamped on the tubes. Some tubes have 2 numbers only (such as 27 or 45), while still others have 1 or 2 numbers followed by a letter or two and then another number (such as 12SK7 or 6V6). Older radios may contain tubes numbered with three numbers (such as 224 or 484). Tube numbers followed by G or GT are glass versions of tubes also made in metal types, and are usually interchangeable with the metal versions. On a piece of paper, jot down the type number of each tube, and the number of prongs on each, in the radio you are examining.

Later on we will learn about the tube numbering system for vacuum tubes and will study in considerable detail just how tubes work. Turn the chassis over and notice how the tube sockets make contact with the tube prongs. Also notice how the wires leading to other parts of the radio are fastened to the sockets.

Every radio has one or more filter condensers which may be in any one of several forms or shapes. Sometimes they are enclosed in metal cans or containers and are located on top of the chassis. In other receivers they may be in cardboard boxes or tubes and located under the chassis. The filter condenser can always be identified by the markings on the container which will usually read something like "50-30 MFD, 150 VDC, 200 VSP", or "16 MFD, 450 V". If your radio has a filter condenser marked as our first example, it means that there are actually two condensers in the container. One of them has an electrical size of 50 MFD (50 microfarads) and the other 30 MFD. Both condensers are rated for maximum steady d-c voltage of 150 volts and they will withstand voltages as high as 200 volts for very short periods of time without breaking down. If the container has just a single condenser in it, it will probably have two wires coming out of it. If there is just one wire, and it is in a metal container, the can itself is the other connection to the condenser. If there are three wires coming out of a cardboard container, the chances are that there are two sections and one of the wires is common to both sections. When the two condensers in a single container are of a different size, the markings will usually give the color of the wires leading to each section. The filter condensers are one of the things that most often wear out in a radio receiver. A number of different types of filter condensers are shown in Figure 7. The condensers shown in Figure 7(A) are the metal cased condensers and are usually mounted in an upright position on the top of the chassis with leads coming out below the chassis. Figure 7(B) shows two types of cardboard cased filter condensers. These types will be located below the chassis.

You will probably find several square aluminum cans mounted in an upright position above the chassis. Keeping the location of these cans in mind, turn the chassis upside down and notice that there is a small round opening directly beneath each can. There will be connecting wires coming through this opening, and if we look through the opening we should be able to see a radio coil or transformer mounted inside the can. There will probably be small holes in the top of these cans and through these holes can be seen the heads of screws. Under no conditions, at this time, should these screws be turned. The metal cans are called shields. Figure 8 shows what is inside one of these shield cans. The component inside of the shield can is called an "I.F. transformer". Later in the training program we will learn just what this component does in the circuit.

If the radio you are using will work on a-c (alternating current) only, you will usually find that it contains a power transformer. It can be identified by its large size and the fact that it contains a number of thin sheets of iron stacked together. Around this iron core are wound many turns of fine wire. The winding may or may not be seen on the transformer in your set (if it has one) depending upon the type of case on the transformer. Figure 9 shows three styles of power transformers. Figure 9(A) is called a universal mounting, Figure 9(B) is called a vertical shielded transformer, and Figure 9(C) is called a flush mounting transformer.

If your radio works on both a-c and d-c, it will not have a power transformer. Sometimes these sets have a third wire in the supply cord. This wire is made of a special material and is quite similar to the heater element of an electric toaster. If the radio uses this, you will notice that the line cord becomes warm when the set is in operation. Should this type of cord become worn or frayed, it must never be cut and shortened, but must be removed and replaced by a similar complete cord.

Although not very common among the table model radios, some of them use a smoothing or filter choke. In appearance, this is quite similar to the power transformer, but can be distinguished from it by being smaller and having only two wires coming out of it. This filter choke consists of a stack of iron laminations or plates around which are wound many turns of wire.

Let us look at the speaker carefully. Notice that it has a paper cone or diaphragm. Carefully touch this and notice that it moves in and out slightly. Turn the radio on and tune in a program. Now touch the speaker lightly and notice that it is vibrating. If we wait for a pause in the program we will notice that when there is no sound coming from the radio, this paper cone will not be vibrating. Let us turn the radio off again and disconnect the line cord. Perhaps our radio has mounted on the speaker a small transformer with two wires going down into the speaker and two wires going back into the radio chassis. This is the output transformer. If this is not the case, we will always see two wires coming out of the speaker. Follow these until you find the output transformer. Figure 10 shows a loudspeaker with its output transformer mounted on it.

Parts Under the Chassis

We will now return to the parts underneath the chassis. In addition to the sockets for the tubes and the potentiometers, switches and coils already mentioned, we will find resistors of all types and sizes, small fixed condensers and a maze of interconnecting wires. The resistors look like small round rods varying from a half an inch to an inch or more in length, having wires coming out of each end of the rod, and have several colors painted on the body of the resistor. Older resistors may have stamped on them their electrical size such as "50,000 ohms" whereas the newer ones have their electrical size marked by means of these colors. We will learn to read this code when we study resistors in greater detail.

The fixed condensers in the radio are probably of several types. A common type consists of round rods larger in diameter and longer than resistors and these usually have cardboard or paper on the outside with their electrical size and voltage rating printed on this wrapper. See if there are any in your radio marked ".05 MFD, 400 VDC". Like resistors, these condensers have a wire coming out of each end. This type of condenser is known as a "paper condenser". Another type of condenser most likely found in the radio is the "mica or postage stamp" type. These are about the size of a postage stamp and have a flat bakelite case with a wire coming out each end. Sometimes they have their electrical size stamped on them, such as .0001 MFD, and sometimes this is coded by means of 3 or 4 colored dots painted on them. We will learn this color code when we study fixed condensers in greater detail.

Look carefully at all the parts on your radio, top and bottom, and be sure that you can name them. This is what we have tried to accomplish so far, for we must know the names and the main points of appearance of every radio part before we can go on. Also, the workmanship under the chassis will tell you a great deal about the quality of the receiver you have. The better sets have the parts neatly wired in and the parts sturdily mounted. When *you* do electronic maintenance work, you should plan to replace the defective parts neatly and securely.

Tools

The repair, construction and testing of electronic and television equipment will require the use of a number of hand tools, quite a few of which you no doubt already have. Before discussing some of the tools which you will be using, let us discuss briefly the care and use of our tools. All tools should be kept free of dirt, grease, rust and any foreign matter. It is difficult to clean a tool after excessive dirt or rust has been allowed to accumulate; therefore its accumulation should be prevented. A good mechanic always wipes his tools regularly with a clean or *slightly* oily cloth. Tools should be used only for the purpose for which they are intended. This would seem to be an obvious statement, but the fact is that far more tools are *ruined* by improper use than are ever *worn out* through proper use. As the various tools are discussed their proper and improper use will be mentioned.

Of the tools used in electronic work, pliers are the most widely used. There are many types and sizes of pliers, each intended for some specific purpose. All types of pliers can be obtained in various sizes. The size of a pair of pliers is determined by the overall length. The most common fault of the untrained workman is to use a pair of pliers as an all purpose tool. Several types of pliers, and their uses are listed below:

1. Side-cutting pliers have square gripping surfaces on the end of the jaws; behind these gripping surfaces are cutting blades. See Figure 11(A). These pliers are used for gripping, splicing, wire cutting, removing insulation, etc . They are not intended to be used as a substitute for a wrench. The most useful sizes of these pliers are the six and eight inch; the larger size being used for cutting and handling larger wire.

2. Diagonal pliers have two cutting edges set at an angle of fifteen to twenty degrees with the length of the tool. See Figure 11(B). They are intended for wire cutting only and also can be obtained in different sizes. Their advantage over side cutting pliers is that, due to their construction, they can cut off a wire closer to its point of attachment than the side cutting pliers. The chief misuse of diagonal pliers is forcing them to cut heavier wire than that for which they are intended. The most common sizes are the five and six inch type which will cut a number 16 hard steel wire. For cutting heavier wire the side-cutting pliers must be used.

3. Long-nose pliers are primarily for light gripping and holding operations and for use in small places. They consist of a pair of long tapering jaws, half round on the outside and flat on the inside. The long-nose pliers may or may not have cutting edges behind the gripping surfaces. See Figure 11(C). If they are forced to do heavier work than that for which they are intended, the jaws will either break or they will bend out of shape and refuse to close firmly on small objects. Five and six inches are the common sizes of long-nose pliers.

4. Needle-nose and chain-nose pliers are similar in appearance and construction to long-nose pliers except that the jaws are circular in cross section instead of semi-circular. See Figure 11(D). They should be used only for forming small loops on the end of wires and for work on instruments.

5. Slip joint pliers have square nose gripping jaws with serrated gripping jaws behind them, close to the hinge. The method of hinging permits the jaws to operate in either of two positions, thereby increasing the gripping range of the pliers. See Figure 11(E). Slip joint pliers are used for gripping fairly large stock and are primarily a make shift tool to be used when the proper tool is not among the mechanic's equipment. They are a possible cause of damage to any surface on which they are used and their use should be strictly limited.

The screwdriver is a tool for turning bolts and screws that are slotted to receive the screwdriver blade. It comes in several styles, the most common being, straight screwdriver, off-set screwdriver and ratchet screwdriver. Figure 12(A) shows an assortment of straight screwdrivers and Figure 12(B) shows an off-set screwdriver. The blade point is designed to fill the slot in the head of the screw. Turning the screwdriver then tightens or loosens the screw. The screwdriver is often wrongly used for prying, opening boxes, or as a chisel.

Two faults can be found with the average man's use of screwdrivers, assuming that he uses them for no other purpose than turning screws. First, is the failure to use a proper assortment of screwdrivers. When a screwdriver too small for a job is used, the blade of the screwdriver does not fit the slot in the screw-head properly. The force necessary to turn the screw is exerted upon too small a surface, and the result is that the head of the screw is damaged.

The other fault in the use of the screwdriver is the improper sharpening of the blade. The two faces of the screwdriver blade should be nearly parallel and the end square. The point of the blade should not be sharpened to an edge like a chisel but should form a rectangle. The blade of the screwdriver should be the same width at the point as the length of the slot of the screw-head for which it is intended, and it should be ground with sufficient thickness to be a snug fit in the slot and yet reach the bottom of the slot. The ideal screwdriver should completely fill the slot for its depth, width and length. The further this ideal is departed from, the greater is the likelihood of damage to the screwdriver and the screw-head. Sharpening is best done upon a small bench grinder.

Radio men are frequent users of drills; such as the hand drill, breast drill, and portable electric drill.

The hand and the breast drill are somewhat alike. The breast drill has a guard plate which is held against the breast while the hand drill has a handle which is ordinarily held in the left hand. Both drills are operated by a hand crank driving bevel gears. The feed is obtained from pressure from the body or hand. A 3-jawed chuck is attached to the spindle and it will usually take up to 3/8 inch straight shank drills.

The portable electric drills come in a variety of sizes and power ratings and the smaller sizes are popular in all shop work. They are made as small as possible and are rated in horsepower (or fraction thereof) or the maximum size twist drill to be used with each machine. A switch is usually so located as to give the operator complete control of the starting and stopping of the motor. Great care should be exercised in operating these machines as the motor will overheat if overloaded and soon burn-out if stalled.

The most generally used drill for boring small holes in metals is the straight shank "twist drill". Twist drills are usually made with two flutes, or grooves, running around the body. This furnishes cutting edges, and the cuttings follow the flutes out of the hole being drilled. The point or cutting end of a drill should be properly shaped at all times, and this can be achieved by grinding carefully on a grinding wheel. A drill grinding tool is available to be used in conjunction with a bench grinder. The size of small twist drills is designated by numbers, and by diameter in fractions of an inch.

Drills are made of high carbon steel especially heat treated to make the cutting edges hard, and are suitable for most all classes of work if properly used and never allowed to become heated. Excessive temperatures cause the cutting edges to lose their hardness and are thus rendered useless by working them too fast (depending on substance being drilled), so that the heat cannot be dissipated. Brass and copper are good conductors of heat so may be drilled faster than iron. Bakelite is a poor heat conductor and requires slow drilling or high speed drills. Monel metal, stainless steel, and other extremely tough materials produce so much heat when drilled that the use of high speed drills is imperative. A drill should be lubricated as should any other metal cutting tool.

Drills made of a special alloy containing tungsten, chromium, and cobalt, are referred to as "high speed" drills. They cost more than ordinary carbon drills, but may be operated at quite high temperatures and still retain their hardness.

Screws, Bolts and Nuts

The term "machine screws" is the general commercial term for screws to be driven into drilled and tapped holes in the assembly of metal parts. When furnished with a nut the combination is referred to as a "bolt". Machine screws are regularly made of steel or brass, with a variety of styles of heads and finishes. Figure 13(A) shows an assortment of round head machine screws.

Prior to the meeting of the Hoover National Screw Commission in 1925, there were no nationally recognized standards for machine screws. This commission established standards, and these standard sizes are now used by all radio manufacturers. The standards so established were subdivided into two main divisions; that is, (1) The American (National) Fine thread series, and (2) The American (National) Coarse thread series. The name "American" instead of "National" is coming into universal use throughout this country.

Screw size refers to the number of the stock of material from which the screw is made; that is, a 6/32 screw means that the screw is made from number 6 stock. (The size is always the first number). This size is different from any other gauge, and has nothing to do with the Brown & Sharpe wire gauge. The 32 indicates that there are 32 threads to the inch.

The length of a screw includes that part of the screw and its head which remains below the surface when properly driven, thus, the length of a round head screw includes none of the head while a flat head screw includes all of the head.

All screw manufacturers list flat, round and oval heads as standard stock items, and some also include fillister, binding, or other types. There are many special heads in use such as ornamental-head screws used to hold loudspeakers, and types with heads designed for special driving devices, etc.

The most common method of driving machine screws is by means of a slot milled into the head of the screw. Such screws are referred to as "slotted head" screws. Some machine screws are made with a hexagonal head (see Figure 13B). With such screws it is possible to use a hexagonal wrench for tightening; thus eliminating the possibility of slipping. Another type of screw head which is becoming increasingly popular is the Phillips head. This screw head is milled with an X-shaped slot which is deeper in the center than at the edges. This type of head requires the use of a special "Phillips" screwdriver, but can be tightened much more securely without the danger of the screwdriver slipping.

Sheet metal screws are made of hard steel, have sharp threads, and are available in the same lengths, diameters, and head styles as are machine screws. An assortment of these screws is shown in Figure 13(B). They are sometimes referred to as self-tapping screws although this is not strictly the case inasmuch as the threads are formed by embossing the work rather than actually removing chips of metals as is done when using a regular tap. It is much better to refer to these screws as "sheet metal" screws. They are driven into punched or drilled pilot holes in sheet metal, fibre, hard rubber, plastics, etc., by means of a screwdriver or hex wrench.

Set-screws are used to fasten the hub of pulleys, wheels, gears, knobs, and tuning dials, etc., to shafts, either permanently or semi-permanently as required. Most set screws are of the "headless" type and are obtained in such lengths that they fit flush with the face of the hub. Figure 13(C) shows an assortment of set screws. Headless set screws may be slotted so that they may be tightened with a screwdriver, they may have the Phillip's recess feature, or may be of the "hollow" type with Allen sockets.

Nuts for machine screws are made of steel or brass and are usually hexagon in shape.

Wings nuts to be tightened without aid of tools, are available in all standard threads.

A thumb nut is a cylindrical nut with the outside knurled.

Wood screws are available with the same type of standard heads as machine screws, and are also made from the same metals, and in the same lengths, finishes, drives, etc. The threads of all wood screws are uniform, making it neither necessary nor desirable to state the number of threads per inch when ordering or describing the screws. They are ordered by diameter, which is specified in gauge numbers of the American Screw Gauge, and length. Wood screws have a so-called "gimlet" point which is more or less self starting in wood; however, a pilot hole reduces splitting.

How Radio Parts are Mounted

With the radio in front of us let us examine how the various radio parts are mounted. The smaller parts such as resistors and condensers are usually supported with their own leads. The tube sockets may be riveted to the chassis or small bolts may be used to hold them in place. Large condensers of the metal cased type such as the filter condensers are mounted with bolts, or with a nut over a threaded portion of the container. Power transformers and filter chokes are bolted in place, usually using the screws which hold the frame to the laminations. Potentiometers and switches used for volume and tone controls are mounted behind the front of the metal chassis with the shaft coming through a threaded section which is held securely in place with a nut.

Notice the manner of interconnecting the various components in your receiver. Radio parts are interconnected with hook-up wire, the wire electrically joining the various terminals. The hook-up wire should be insulated along its path, but is made bare and clean where it comes in contact with the terminals. Push-back braided cotton-covered wire in sizes 16 to 20, B & S gauge, is easiest to handle and is the most popular. To make a connection with this wire, the insulation is pushed back as shown in Figure 14(A). When the insulation cannot be pushed back far enough with the fingers, it will be easier to grasp the bare end of the wire with a pair of long-nosed pliers. Then, holding the wire in this manner, it is a simple matter to push the insulation back with the fingers as far as required. This is illustrated in Figure 14(B). After the connection has been made, the insulation should be pushed back over the bare wire right up to the terminal.

Hook-up wire having rubber or plastic insulation is often used as the leads of radio parts such as transformers and filter condensers. To make connections to these leads the insulation is crushed with pliers and then removed with diagonal cutting pliers or a knife. Care should be taken so that the wire is not nicked or cut in removing the insulation.

Notice that when the connecting wires are connected to tube socket terminals they are not just held against the terminal and then soldered, but are "crimped" to the terminal before they are soldered. The purpose of crimping wires to a terminal is to insure a strong mechanical connection, as solder alone should never be depended upon to keep the connection secure. If the terminal has a hole it it, the hook-up wire can be bent into a half-loop with long-nose pliers, and the tip of this loop inserted through the hole. Then the wire is squeezed or crimped against the terminal and the unused portion of the wire cut off before the solder is applied. In case the terminal is of the lug type and does not have a hole, the wire is also made into a half-loop and crimped against the terminal. It is even better to wrap the wire around the terminal a time or two and then crimp it from both sides. This is illustrated in Figure 15.

Electrical connections should be soldered in order to insure a good low resistance path under all conditions. For best results, make it a rule to solder every connection you make, even if you intend it to be a temporary one. Solder is made up of tin and lead and melts readily when heated with a hot soldering iron. Solder cannot make a permanent connection with any metal when the metal is dirty or has a layer of oxidation on it. A soldering paste or *flux* has been developed which, when heated, removes all dirt, grease and oxidation and allows the solder to adhere to the metal. Rosin flux rather than acid flux should be used in electrical wiring, and solder is available which contains a core of rosin flux. Since the rosin has a lower melting point than the solder, the rosin melts first and flows out and cleans the metal before the solder begins to flow.

To provide the necessary heat to melt the solder, electronic technicians use an electrically heated soldering iron. These irons are rated in the electrical energy they consume, with irons ranging from 60 to 100 watts being the most popular. The heating element of the iron is located inside a metal barrel and the heat travels down to the copper tip which does the actual soldering.

Your first Home Laboratory assignment will provide you with the necessary equipment and complete instructions for soldering electronic equipment. Examine the soldered connections in the receiver before you. Notice that the solder is not "stacked up" on the terminals but that there is just enough to hold the connections firmly. After you have finished the soldering practice provided in your first Home Laboratory assignment, you should be able to make solder joints comparable in quality to those in your receiver.

If you have examined your receiver thoroughly and are satisfied that you can identify all of the parts, re-install the chassis in the cabinet. Be sure to re-connect everything just as it was before removal of the chassis. Plug the power cord plug into the receptacle and again "rough check" the receiver to see that it operates as well as it did before you started working on it.

Summary

This assignment has enabled you to take a real step forward toward your goal of becoming an electronics technician. You have learned to identify the parts in a radio receiver which, as pointed out previously, are the same as those used in television equipment and in industrial electronic equipment. You have also learned the proper use of the various tools employed in electronic work.

The radio which you have examined in this assignment contains a wide variety of electronic parts. Quite obviously, however, it does not contain all of the different types of parts which are employed in the many thousands of kinds of electronic equipment in use. Just as the information you have gained in this assignment will be of great value to you as you proceed with your training, so will any additional information you can gain regarding the appearance of various electronic components be of value to you. Thus it is advisable for you to become familiar with the appearance of as many different electronic components as possible. One very practical way of obtaining this knowledge is to look over - in fact, study - one or more electronics parts catalogs. These catalogs are issued by many electronics mail-order supply houses. If you will send a postcard to one or more of the following firms, you will receive their catalog showing pictures, descriptions and prices of many types of electronic equipment and parts:

Allied Radio Corporation
100 N. Western Avenue
Chicago 80, Illinois

Concord Radio Corporation
45 Warren Street
New York 7, New York

Burstein-Applebee Company
1012 McGee Street
Kansas City 6, Missouri

Walter Ashe Radio Company
1125 Pine Street
St. Louis 1, Missouri

Another suggestion which we feel may be of great value to you is that, from time to time, you obtain one or more of the radio-TV-electronics magazines on the newsstand. Look over the various electronics magazines, and decide which "suits you best." Then subscribe to this magazine, and read it regularly. You will find that the general information you obtain from technical magazines will aid you greatly in your advancement in the electronic field. Two magazines which are recommended for general reading are "Radio and Television News" and "Radio-Electronics."

In the next assignment you will use the information you have learned here in a very interesting way. Various symbols which can be easily drawn by hand and easily printed are used to represent electronic parts in circuit diagrams. In the next assignment you will learn to identify these various symbols, so that you will be able to "read" and draw electronic circuit diagrams.

POWER TRANSFORMERS

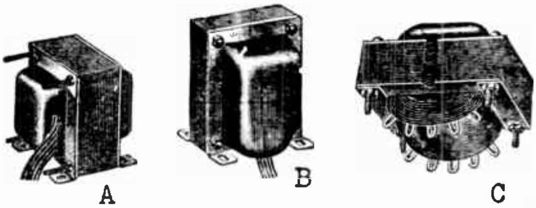


FIGURE 9

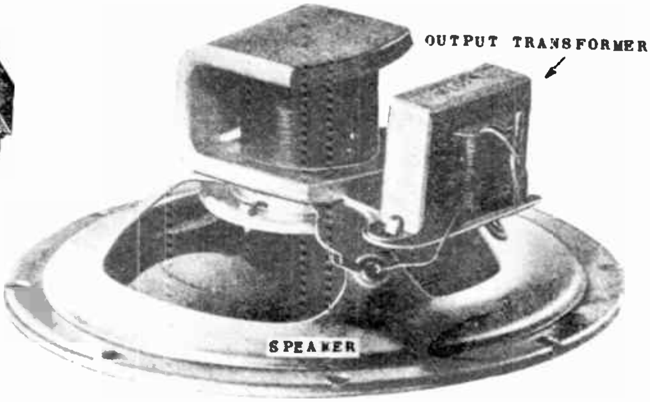


FIGURE 10

FIGURE 11-A

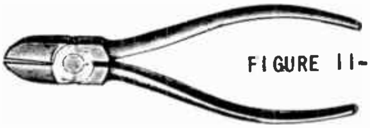


FIGURE 11-B

FIGURE 11-C

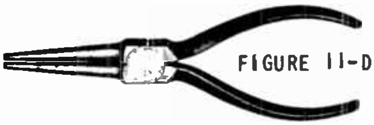


FIGURE 11-D

FIGURE 11-E

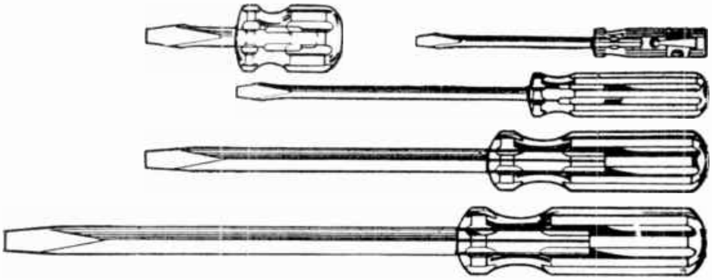


FIGURE 12-A

FIGURE 12-B

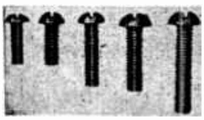


FIGURE 13-A

FIGURE 13-B

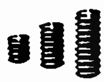


FIGURE 13-C

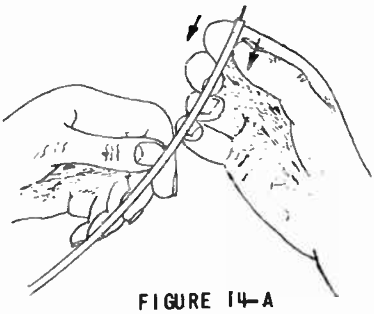


FIGURE 14-A

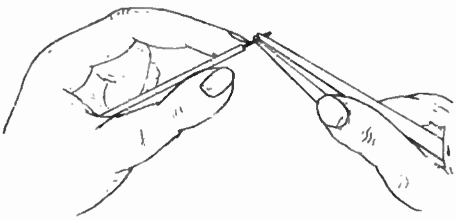


FIGURE 14-B

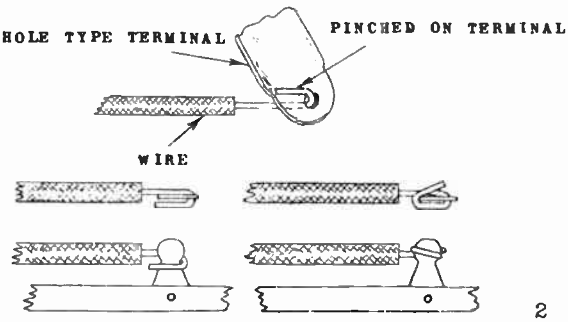


FIGURE 15

Test Questions

Be sure to number your Answer Sheet Assignment 2.
Place your Name and Associate Number on *every* Answer Sheet.
Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. What should be done when "Rough Testing" a radio receiver to see that it is in proper operating condition? Please list the various steps briefly.

2. What is the proper name of the component that controls the volume (and sometimes the tone) of a radio receiver?

3. How can it be determined which of the components in a receiver are the filter condensers?

4. What do the colors painted on a resistor indicate?

5. If there is no set screw in a knob, how should the knob be removed?

6. What are the tube type numbers in the set which you have examined? How many base pins does each tube have?

7. In radio work what are long-nosed pliers used for?

8. If you wanted to cut a *large* wire, should you use a pair of diagonal pliers, or a pair of side-cutting pliers?

9. If you found a tubular shaped part under the chassis of a radio receiver labeled .01 MFD-600V DC, what would be the proper name for this radio part?

10. If you found a part on the top of the chassis of your radio which was in a square aluminum shield can, what would the proper name for this component be?

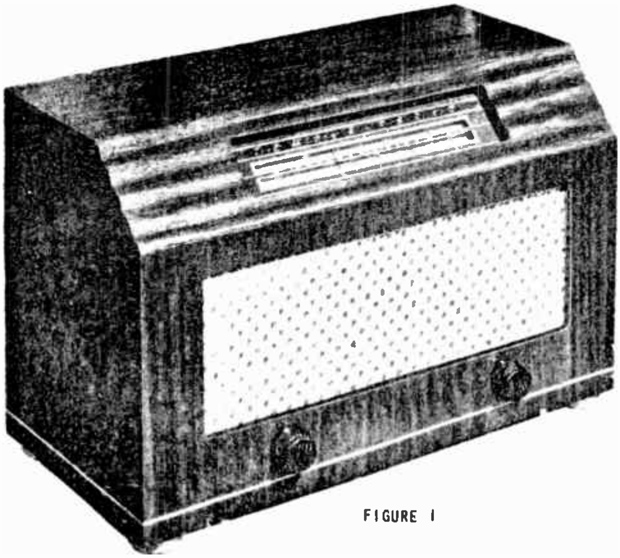


FIGURE I

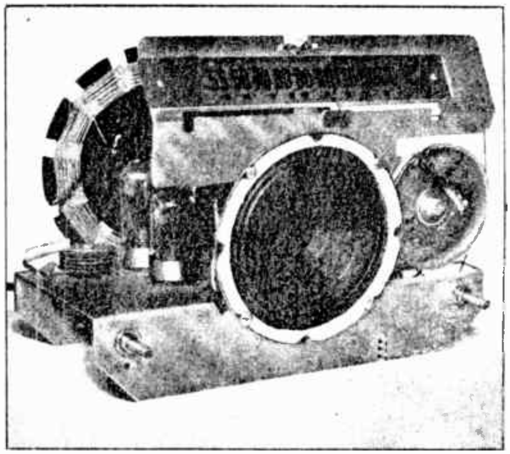


FIGURE 2

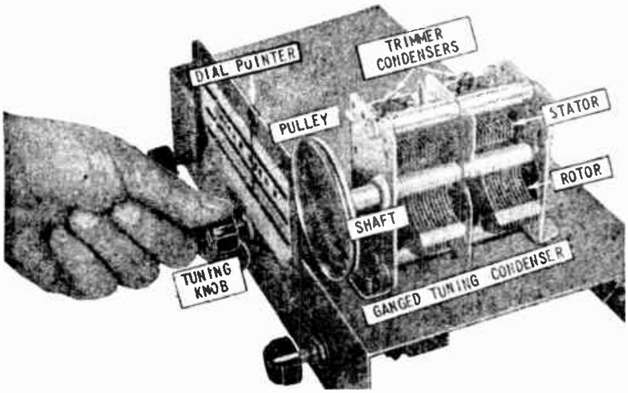


FIGURE 3

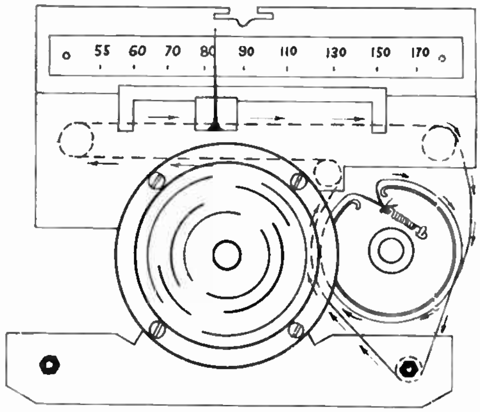
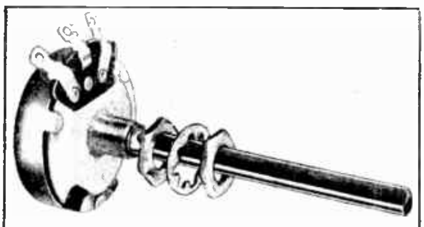
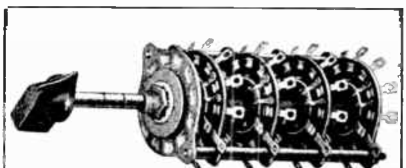


FIGURE 4



POTENTIOMETER

FIGURE 5



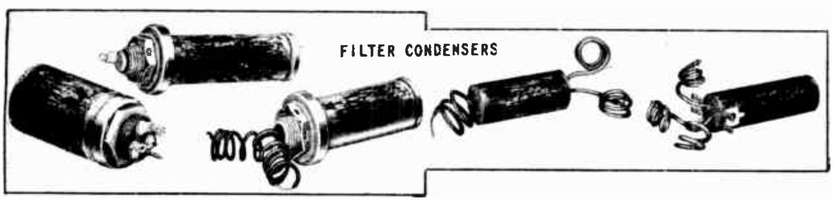
ROTARY SELECTOR SWITCH

FIGURE 6

SHIELD CAN

I-F TRANSFORMER

FIGURE 8



FILTER CONDENSERS

FIGURE 7-A

FIGURE 7-B

Electronics

Radio

Television

Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

CIRCUIT DIAGRAMS AND HOW TO READ THEM ASSIGNMENT 3

ASSIGNMENT 3

CIRCUIT DIAGRAMS AND HOW TO READ THEM

We have now reached a point in the training where it will be necessary to learn some of the symbols which are used in electronics, radio, and television diagrams. Radio men have long employed a written sign language since, in this way, it is possible to show every connection in a complicated electronics circuit on a small piece of paper; whereas, if a written description were employed, it would require many pages. From our experience with the radio receiver of the last assignment we can easily see why a photograph, or even a series of photographs would not give us the complete answer on the wiring and parts of even simple radio receivers, much less anything very complex. For example, no photograph could possibly give the electrical size of the resistors and condensers and certainly no photograph or pictorial drawing could show the component parts mounted under other parts.

The system employed in electronics diagrams is very simple, and once you get fully acquainted with it, you will appreciate its value. You cannot work on electronics and television equipment or study the literature without having a knowledge of this system. Therefore, it is absolutely necessary that you learn it so that you can progress smoothly in the training.

In the last assignment we got an idea of what the various component parts of a radio receiver look like, and we saw that these component parts were electrically joined together in some definite pattern by means of hookup wire. There are hundreds and hundreds of different ways to connect these various parts together to form different circuits. Obviously, no one can remember all these ways, or know in advance how the designer of the equipment is going to arrange this particular circuit. Thus, it is necessary that a universally accepted system be used in order that a piece of electronic equipment manufactured in one part of the country may be efficiently serviced in another. When you have learned this symbol system, you can look at an electronics circuit diagram and determine at a glance just what you want to know.

In the last assignment we saw that fundamentally a radio circuit consisted of a limited number of basically different parts (condensers, coils, resistors, vacuum tubes, etc.) and that these parts were connected together by means of wire and mechanical fittings such as screws, nuts, rivets, clamps, etc. Different electrical sizes of these parts were used in the same equipment, but basically, we could count the number of really different parts on the fingers of our hands. Thus, it can be seen that learning about these parts will not be as difficult a job as it might seem.

Each of the different parts which make up a radio receiver or an electronic unit have certain characteristics which are called *properties*. As we progress through this training, we will study these properties, since the action of an electronics circuit is controlled by the properties of the parts used in it. For example, consider wire. Every piece of wire has length. Thus, length is a property of the wire. A wire when heated is longer than it was when cold; so another property of wire is its expansion under the influence of heat. Every wire offers resistance or opposition to the flow of an electric current through it, so its resistance is a property of the wire. Every electronics circuit uses many different sizes and kinds of parts and a number of properties are associated with each of these parts.

kinds of parts and a number of properties are associated with each of these parts.

When you are called upon to locate and repair a defect in a radio or television receiver, amplifier or transmitter, you will be required to check a number of different properties in a systematic manner. It is difficult to do this in a confusion of wiring in actual equipment, but with the aid of a diagram, you can check off each circuit as you test it.

Before you can check the properties of the parts used in any equipment, you must know what kind of a part is used and where this part is located electrically. An examination of the inside of the equipment will not always give you this information. Even an experienced electronics technician may have trouble distinguishing between a filter choke and a condenser when it is sealed inside a can or container because in many instances their appearances may be similar. For this reason, it may be necessary to refer to a diagram to learn, first, what parts are being used, and second, how these parts are connected. Then you can start at some point which you can identify and in this way trace the wiring to the actual part in question.

Schematic Diagrams

The electronics and television technician almost invariably works from a schematic diagram. Such a diagram is shown in Figure 1, which is the diagram for a typical five-tube table model broadcast receiver. Every radio set includes a model number, or name by which it may be identified. This model number should not be confused by the serial number which is a number which the manufacturer has assigned to that particular set at the time the set was made. Often the manufacturer will make changes in a given model, and by keeping a record of the serial numbers of the units made, both before and after the change was made. they can tell just what parts are used in any set of any particular model.

This brings up the matter of how the serviceman or technician may obtain these schematic diagrams. Thousands of radio sets have been made in the past and diagrams are available for most of them. On the other hand, some manufacturers have gone out of business and no diagrams are available for their radios from any source. In cases of this kind the service man must rely on his general knowledge and trace out the circuits to the best of his ability. Fortunately, this is not often the case.

There are also some radios in use which are known as "orphans" - that is, all the identifying marks and numbers on the set have been removed. Here the service man is up against a blank wall in obtaining a diagram for the set. Either he must rely on his general knowledge of radios or draw his own schematic diagram by tracing out the actual wiring of the parts. Such sets are more expensive to repair because the service man has to spend more time on them, but fortunately, they too, are in the minority.

A complete file of all published radio diagrams covering the many thousands of different radios which have been made will run into many volumes. They are available from radio parts jobbers and wholesalers and from the publishers. In the larger cities, local public libraries keep these manuals on file for public reference. The best known group of volumes of radio receiver circuits is the series known as "Rider's Perpetual Trouble Shooter's Manuals" and is published in twenty-five volumes covering nearly all radio sets which have been made. "Supreme Publications" print a series of six manuals which they claim contain the most often needed diagrams, and being smaller, are not nearly as expensive. The Howard W. Sams Institute started a series of service folders at the end of World War II. They are more complete than either of the above manuals, but, of course, cover only postwar receivers.

Most radio manufacturers will provide free, or will sell at a nominal cost, diagrams of all sets which they have manufactured. The service man, in writing to the manufacturer for these diagrams, should write on his own printed business stationary, which is usually sufficient evidence to prove that the writer is entitled to use them. This is necessary to protect the manufacturer from having to send out thousands of diagrams for which there is no actual use.

Rider's, Sam's, and Wallace's Teleaides also publish schematic diagrams on practically all TV receivers. This information is of great value to the TV technician. In most instances the manufacturers of Industrial Electronic equipment provide Service Manuals to their customers. These manuals include schematic diagrams, and in addition provide adjustment procedures, and service hints for the technician.

Pictorial Diagrams

There is another type of diagram which some electronics manufacturers include in their service manuals. It is known as a pictorial diagram, and is illustrated in Figure 2. This type of diagram is most useful in showing the actual physical layout of parts. Beginners in radio have a tendency to rely on the pictorial rather than the schematic diagram, but this is not a good habit to get into since these pictorial or wiring diagrams are not available for all equipment. Actually, you can find out with a glance everything you need to know about a piece of electronic equipment from the schematic diagram after you learn to read it, whereas much study is required when the wiring diagram is used alone, This pictorial diagram should only be used in conjunction with the schematic diagram to show the layout of the parts - never used alone. Experienced technicians seldom refer to the pictorial diagram, but rely almost entirely on the schematic diagram.

Learning to read schematic diagrams is mostly a matter of becoming familiar with the major symbols which are used in electronics and television. There is a large number of symbols in use, but the principal seven are: (1) resistors (both fixed and variable), (2) condensers (fixed and variable), (3) inductances (coils and transformers), (4) batteries and cells, (5) vacuum tubes, (6) microphones, pickups, and speakers, and (7) switches of all types. Thus, by memorizing the symbols for these, you will be able to read any schematic diagram.

Resistors

Resistors are manufactured in a great number of shapes and sizes. Figure 3 illustrates a number of resistors and the schematic symbols used for the various types of resistors.

The schematic symbol shown in Figure 3(A) is for a *fixed resistor without taps*. The illustrations, numbers 1 through 10, in Figure 3, are fixed resistors which would be illustrated in a schematic diagram by the symbol shown in Figure 3(A). A brief description of each of these resistors follows.

Resistor 1 is a carbon resistor, available in wattage ratings from 1/4 watt to 2 watts, depending upon the physical size. This style of resistor is of an old method of manufacturing and will be found in older models of receivers.

Resistor 2 is a carbon or metalized resistor, available in wattage rating of 1/4 watt to 2 watts, depending upon the physical size. This resistor is manufactured by a new process and will be found in equipment of modern design.

Resistor 3 is a precision wire wound type of resistor used for meter multipliers and shunts, and in laboratory equipment where accuracy of the resistor value is important.

Resistors 4 and 5 are two forms of wire wound resistors which are available in wattages of 5 watts and above.

Resistors 6 and 7 are called wire-wound strip resistors and are usually of the low power type (less than 5 watts).

Resistor 8 is an enclosed ballast resistor, or plug-in resistor, used in some receivers to adjust automatically the power line voltage or to maintain it within narrow limits. Often this type of resistor is enclosed in a metal or glass envelope with base pins and from the outside looks exactly like a vacuum tube.

Resistor 9 is a wire wound flexible type of resistor and will be found in small receivers where space is limited.

Resistor 10 is called a power-cord, or line-cord resistor. Notice that there are three wires in the cord. Two of these are the usual two lines used to connect electrical equipment to a receptacle. The third wire is resistance wire. This type of a resistor is used with some types of table model radios and will be discussed again later in the training program.

As was previously stated, the symbol (A) of Figure 3 is used to indicate any of these resistors just described, in a schematic diagram.

The symbols (B) and (C) of Figure 3 are used to indicate *fixed resistors with taps*. The symbol (B) represents a fixed resistor with one tap, while the symbol (C) represents a resistor with three taps. Resistors 11, 12, and 13 in Figure 3 are tapped resistors which would be represented in a schematic diagram by symbols (B) and (C).

Resistor 11 is a center-tapped wire-wound resistor of the power type. Symbol (B) is used to represent this resistor in a schematic diagram.

Resistor 12 is a center-tapped wire-wound strip resistor. This type of resistor will be found in older models of receivers only. Symbol (B) is used to indicate such a resistor.

Resistor 13 is a wire-wound power type resistor with three taps. The symbol used for this resistor is shown at (C). Resistors with more than three taps would be represented by a symbol such as illustrated at (C) except the proper number of taps would be indicated by the lines coming off of the resistor.

The symbol shown at (D) in Fig. 3 is for a resistor with an adjustable tap. Such a resistor is illustrated by resistor 14. On this type of resistor there is a strip along the length of the resistor where the insulating material is left off during manufacturing. A metal band is provided which makes contact with the bare resistance wire when the bolt in this metal band is drawn tight. To adjust the tap on this resistor it is necessary to loosen the screw in the tap band, move the band to the desired point on the resistor, and then again tighten the screw. This type of resistor may have several adjustable taps; the number of taps will be indicated by the number of taps on the symbol shown in Figure 3(D).

The symbol (D) in Figure 3 is also used to represent the variable resistor 15 in Figure 3. The proper name for this variable resistor is *potentiometer.* A potentiometer has three connections as may be noted from the illustration. The center lug connects to the variable "arm" of the potentiometer and the two outer lugs connect to the ends of the resistance. Potentiometers may be either wire-wound or carbon. (Potentiometer is pronounced: Po-ten-shi-om-i-ter)

The symbol at (E) in Figure 3 is used to represent the variable resistor 16. This variable resistor is called a rheostat. A rheostat normally has only two connection lugs as may be noted in the illustration. One of these lugs connects to one end of the resistance element, and the other connects to the movable arm. Rheostats use wire-wound resistance elements.

The symbol shown at (F) in Figure 3 is sometimes used to denote a rheostat or a potentiometer when it is connected as a rheostat. That is, when only the movable arm and one end of the resistance element are connected to the circuit.

Connections to resistors are made in two general ways as may be seen in Figure 3. In resistors 1,2,3,4,5,7,9,11, and 12, connections to the actual resistance element are made through wires which are commonly called "pigtails". In resistors 6, 13, 14, 15, and 16, the connections are made to terminal lugs. Resistors 8 and 10 do not fall into either of these general categories.

Condensers

Figure 4 shows the symbols for various types of condensers. There are two general classifications of condensers: (1) fixed and (2) variable. For the first classification to apply, the condenser must have a definite fixed value which is not changeable. The second classification applies to condensers which have a changeable value between certain extreme minimum and maximum values. There are many types of condensers represented by these two classifications.

First of all in Figure 4 there are illustrated several forms of fixed condensers. The symbol for these is shown at (A), the same symbol being used to denote any type of fixed condenser. Condensers 1, 2, and 3 of this group are mica types of fixed condensers in moulded bakelite form. The word mica refers to the type of insulation between the metal condenser plates, condensers consisting of a sandwich of two or more metal plates filled with an insulator of some kind. These mica condensers are usually used in high frequency circuits where very few losses can be allowed, and their electrical size varies from about .1 to .000001 mfd. (MFD. is an abbreviation for microfarad. This term will be taken up in a future assignment).

The next group of condensers, 4 and 5, are of the paper type. These range in capacity from about .001 to 4 mfd and are used to filter low frequency circuits, since they have medium loss qualities and yet perform satisfactorily. Sometimes, two or more of these condensers are found in the same container. Condenser number 6 is a two-section paper "bathtub" type, and may be represented by a symbol such as B, where each symbol in the group represents a separate condenser.

In the next group, from 7 through 10, the electrolytic condenser type is shown. There are two kinds: (1) the wet or liquid type, and (2) the "dry" type, which is actually no more dry than is a flashlight battery. Electrolytic condensers vary in size from about 4 to 100 mfd., and are principally used in power circuit filtering and in circuits where a large capacity in a small space is required. They always have polarity -- that is, their positive and negative terminals must be connected to the proper positive and negative points in the circuits where they are to be used. The symbols are the same for both wet and dry types and sometimes the polarity signs are omitted altogether. If the polarity signs are omitted, the negative plate is indicated by the curved line in the symbol. Symbol (C) represents a single unit whereas (D) represents a multi-section unit consisting of two condensers in the same container.

Condenser 11 is a type of adjustable or semi-variable condenser known as a trimmer, padder, or a compensating condenser. The symbol for this type of condenser is shown at (E). This type of condenser may range in value from about 3 to 2000 $\mu\mu$f (micromicrofarads). Such condensers are usually used in conjunction with fixed condensers to enable the combination to add up to an exact value of capacity that is required by the circuit design.

Condenser 12 in Figure 4 illustrates a variable condenser. This is the type of condenser which you adjust when you tune from one radio station to another and which was examined in the last assignment. The symbol for a single section variable condenser is the same as that for the semi-variable condenser, and is shown at E in Figure 4.

These condensers range in electrical size of from about 3 to 15 $\mu\mu$fds for the minimum range on up to about 150 to 450 $\mu\mu$fds for their maximum range. Few single-section variable condensers are used in modern radios, the average being the two and three gang types. The symbol for a two gang condenser is shown in Figure 4(F). Note that in the figure dotted lines are used between the two sections, indicating that both sections are controlled by one shaft.

Unfortunately (and this is especially true with condensers) there are sometimes more than one symbol which may be used to designate a certain radio component. Power engineers prefer one type of symbol, while an electronics technician uses a different symbol. In 1944, a standardization program was undertaken in order to standardize on a specific group of electronic symbols to be used by both power and electronics men. These standarized symbols for condensers are those shown in Figure 4(A, B, C, D, E, and F). However, many of the diagrams which you will encounter in books and magazines were either drawn before 1944 or the author has ignored the standard symbols, so you should be able to recognize the non-standard forms Figures 4 (G, H, I, J, and K) show some of these older non-standard symbols for fixed condensers and the non-standard symbol for variable and semi-variable condensers is shown in Figure 4 (L).

Inductance

The subject of the symbols used to represent various types of inductance can be divided into two general categories. These two categories are coils and transformers. Since transformers are merely combinations of coils, we shall consider the symbols for coils first.

Coils

Figure 5(A) shows the symbol used to indicate an air core coil. The coils number 1 and number 2 in Figure 5 are typical air core coils. Coil number 1 is a multi-layer coil, and coil number 2 is a single layer coil. The coil number 3 in Figure 5 is also an air core coil, but is normally used in the radio circuit in a different manner than coils number 1 and 2. This type coil is called an RF choke and usually has RFC printed near the symbol as shown in Figure 5(B). As we discovered in our last assignment, a coil is made up of a number of turns of wire on a form. The number of loops in the symbol used to represent a coil *does not* indicate the number of turns on the coil. There is no attempt to indicate the size or shape of the coil by the size of the symbol. Symbol size and the number of loops shown are determined by the space available on the diagram.

The symbol for an iron core coil is shown in Figure 5(C). Coil number 4 in Figure 5 illustrates the appearance of a typical iron core coil. In this coil the turns of wire are wound around an iron core made from sheets of iron stacked together. The turns of wire are insulated from each other, and are insulated from the core by special insulating paper. Iron core coils are often called *chokes*.

Transformers

When two or more coils are brought close together, a transformer is formed. These two or more coils will usually be wound on the same form. The symbol shown in Figure 5(D) is used to indicate an air core transformer. Illustration number 5 in Figure 5 is a typical air core transformer. Illustration number 6 shows a cut-away view of this same transformer inside a shield can. The dotted lines shown around the symbol in Figure 5(D) are used to indicate that the transformer is surrounded by a shield can. In a great majority of cases, the dotted line will be omitted, although the transformer is usually shielded.

The symbol in Figure 5(E) is used to indicate an iron core transformer. Such a transformer is shown in illustration number 7 in Figure 5. This transformer has only two windings as indicated by the symbol. In some transformers one of the windings is tapped at its center. The symbol for such a transformer is shown in Figure 5(F).

Some transformers, such as the power transformers, have more than two windings. The symbol for a power transformer is shown in Figure 5(G). This symbol represents a transformer with four windings. One of these windings is center-tapped. A typical power transformer is shown in illustration number 8 of Figure 5. In the symbol shown in Figure 5(G), the winding to the left of the two straight lines is called the primary winding, and the windings to the right of the straight lines are called the secondary windings. The primary winding of a transformer is the winding into which electrical energy is supplied. The energy is taken from the transformer from the secondary winding or windings. The straight lines indicate the fact that an iron core is used.

The symbol shown in Figure 5(H) is for a powdered iron core transformer. These transformers are used when high frequencies are employed. The arrows through the straight lines indicate that the powdered iron cores are variable.

Batteries

Figure 6 shows various kinds of batteries and the symbols used to represent them. The symbol shown in figure 6(A) represents a single cell, such as the dry cell shown in the illustration number 2 in Figure 6. The short heavy line is used to represent the negative terminal of the cell and the long line represents the positive terminal. The symbol shown in Figure 6(B) is used to represent a battery, which is really a group of cells. There is no fixed rule as to the number of individual cell symbols to use to represent a battery. Furthermore, there is no relationship as to the number of individual cell symbols and the voltage of the battery. The voltage value is usually written alongside the symbol as shown in Figure 6(B). The polarity signs are often omitted, in which case the polarity is indicated by the size of the lines as mentioned previously.

Radio batteries are usually classified as "A", "B", and "C" batteries, which is a designation which more or less grew up with the radio industry from the days when all radio receivers were battery operated. An "A" battery usually refers to the one used to heat the filaments of the tubes and it had a voltage ranging from 1½ volts to 12 volts, depending upon the radio. A "B" battery refers to a larger battery usually having a voltage of 45 volts or more. It was used to supply the voltage to the plates of the tubes. A "C" battery is usually of the low voltage - low current type and was used to apply a negative voltage to the grid of the tube. It ranged in voltage from about 1½ to 7½ volts. The battery shown in illustration number 1 in Figure 6 is a "C" battery. Illustration number 3 shows a "B" battery and illustration number 4 shows a familiar storage battery. Storage batteries were used for "A" batteries in early radios and are still used in auto radios.

Vacuum Tubes

Let us next consider some of the symbols for vacuum tubes. Like the other components mentioned in this assignment, do not become alarmed or confused about some of the terms which we will use here - a full explanation of them will be given later on in the course.

There are many kinds of electronic and television tubes in use and to attempt to list all of them in this assignment would require considerable space and would involve a special study of tubes - a subject which will be taken up later on in the training. Here, we are concerned with their symbols, and from this viewpoint it is possible to show most of the tube types. Manufacturers of electronic equipment have not all adopted the standard method of drawing tubes, but all systems are so nearly alike that it is not possible to mistake a tube for some other radio part. In this training we will use the standard symbols adopted in 1944.

Most systems of drawing tubes show the tube elements enclosed within a circle, as indicated in Figure 7. This circle is supposed to represent the glass or metal envelope of the tube.

One type of vacuum tube (a triode) has in the envelope a single filament, a grid, and a plate; these are called the elements of the tube. The symbol for such a tube is shown in Figure 7(a); (b) represents the glass envelope, (c) the filament, (d) the grid and (e) the plate. Each of these elements is provided with only a single connecting terminal which in actual practice generally leads to an individual prong at the base of the tube. (Of course there are two terminals provided for the filament).

You must bear in mind that a schematic diagram uses symbols, and these do not always show the location of the prongs and the locations of the actual parts which are connected to the prongs. The information which shows where and how the tube prongs are located for a particular tube may be found in tube manuals, one of which will be sent to you a little later in the training. Suppose that the tube symbol shown in Figure 7(A) appears in a schematic diagram and is marked to indicate that this is meant to be a type 30 tube. By referring to a tube manual, under type 30 tubes we would learn that the type 30 tube has a four prong base and that prongs 1 and 4 are connected to the filament, prong 2 is connected to the plate and prong 3 is connected to the grid. Looking at the bottom of the tube with the two heavier prongs closest to you, the heavy prong on the left is number 1, the next one going clockwise around the tube is 2, etc. Thus, 1 and 4 are the two heavy pins and would connect to the filament. Figure 7(F) shows the schematic symbol for another type of tube which has no grid. This tube is called a diode. Its two elements are the filament and the plate.

Figure 7(G) represents another vacuum tube with an additional element placed close to the filament, or heater as the filament is called in this type of tube construction. This new element is known as a cathode. This tube is called a triode also, as the cathode is performing the same function as the filament in the triode of Figure 7(A). The tube of Figure 7(H) is called a tetrode and contains still another new element - a second grid placed close to the plate and called the screen grid. The tube of Figure 7(I) is called a pentode, and contains three grids in all, the third grid being placed between the screen grid and the plate. This third grid is called a suppressor grid.

Other types of vacuum tubes may have more grids or plates, and it is not unusual to find two or three tubes (for example, two triodes) all located in the same glass or metal envelope. These are known as dual purpose tubes.

Electron tubes are manufactured to perform a specific task or job and although they may have minor differences, they may all be classified into distinct types. Thus we may see tubes listed by the use they were designed for, as amplifiers, oscillators, detectors, etc. Any one particular classification may be filled by more than one type tube. For instance, an amplifying tube may be a triode, tetrode or pentode.

Microphones, Pick-ups and Speakers

Microphones are used in public address systems, home recorders, and broadcasting equipment, so we should be able to recognize the microphone symbol when we see it in a schematic drawing. There are many variations of the microphone symbol depending upon the type of microphone used but all these are recognizable as a microphone. The general symbol for a microphone is shown in Figure 8(A).

A large number of radio receivers have in conjunction with them a phonograph record player. The arm which holds the needle and rests on the record is called the "pick-up". There are two types of pick ups in common use: The electromagnetic, the symbol for which is shown in Figure 8(B), and the crystal type, represented by the symbols of Figure 8(C) and (D).

There are several types of loud speakers in use at the present time. The accepted symbol for a loudspeaker is shown in Figure 8(E). Variations in this symbol will be found, but a speaker symbol is easily recognized by the cone shaped part which will always be found. The symbol for a pair of headphones is shown in Figure 8(F).

Switches and Miscellaneous

In Figures 9(A) through (D) are shown the schematic symbols for various types of switches. Symbol (A) is for a two gang rotary type of selector switch. Symbol (B) shows a single pole single throw toggle switch. (Usually abbreviated SPST). Symbol (C) shows a single pole double throw (SPDT) switch and symbol (D) represents a double pole double throw switch (DPDT).

Symbol (E) in Figure 9 indicates the accepted symbol for an antenna or aerial. The term antenna is preferred to aerial by all knowing radio and television technicians. Symbols (F) and (G) are non-standard symbols for an antenna which are widely used. Symbol (H) is for a loop antenna such as those used in modern table model radios. The symbol shown in Figure 9(I) is to indicate the ground connection. The symbol shown in Figure 9(J) is a non-standard ground symbol which is used quite often. In a radio the ground symbol indicates a connection to the chassis.

A crystal such as is used in a transmitter is represented by the symbol of Figure 9(K). Voltmeters and ammeters are indicated by Figure 9(L) and 9 (M) respectively. Pilot lamps are shown in Figure 9(N) and neon lamps are shown in Figure 9(O). Fuses are represented by the symbol of Figure 9(P).

Shielding of any component is indicated by a dotted line as was shown in Figure 5(D). The symbol for shielded wire is shown in Figure 9(Q).

Methods of Showing Connections

There are two general systems of indicating the actual wiring of radio circuits, as illustrated in Figures 10 and 11. These two circuits indicate wire connections from the filament winding of a power transformer to the filament terminals of two vacuum tube sockets. (Only a portion of the power transformer is shown). We have also shown part of the connection to the plate terminal of one tube. In Figure 10 notice especially that large dots appear at certain places on the wiring. These dots mean that an actual wire connection is intended at this point on the circuit. Notice that where the plate wire crosses the filament wires there are no dots and hence we know that these wires are not connected. Figure 11 shows the method of indicating connecting and non-connecting wires that was approved in 1944. In this system, half circles or loops mean no connection. That is, when two or more wires cross without these loops a connection is indicated, but where a loop is used no connection is indicated. You should study these two systems very carefully until you are sure you understand the principles of each, and the differences between the two. In some cases you will find a combination of these two systems; that is, loops (or jump-overs as they are sometimes called) are used to indicate no connections and dots are used to indicate connections. Such a system is used in Figure 12.

Identifying Symbols in a Complete Schematic Diagram

Let us now analize the schematic diagram of the typical radio receiver shown in Figure 1 of this assignment. When you first opened this page of your assignment you were probably completely mystified by this diagram. Now a careful examination of this circuit will reveal that it is composed of a number of the circuit symbols which we have taken up in this assignment. Let us identify a few of the parts in this diagram. Starting at the upper left corner of this diagram the first symbol we encounter is the ground symbol. The next symbol we find is the component labeled C_{10}. This is the symbol for a variable condenser. The size of this condenser is 70 mmfd (micromicrofarads). Symbols L_1, L_2, and L_3 are air core coils. The first symbol which we encounter that appears strange to us is the symbol labeled S_1. This is the symbol for a special type of rotary switch. As this switch is rotated, B and C are shorted together. (Connected together). This is called a shorting switch. Proceeding to the right in our diagram we find a lead which goes to C_1 and C_3. C_1 is one section of a ganged tuning condenser. (Condensers are often called capacitors). C_3 is a semi-variable condenser.

The next circuit component that we encounter is the type 6A7 vacuum tube. This has a heater, a cathode, 5 grids and a plate. The little protrusion through which one of the grid leads enters indicates that this tube has a grid cap on the *top* of the tube. The dotted line around the tube indicates that this tube has a shield can around it. This shield can is grounded as indicated by the ground symbol. Directly below the 6A7 tube is a resistor, labeled R_2, 47,000 ohms. This is the *electrical size* of the resistor. Notice that this resistor is connected between the grid nearest the cathode, and the cathode of the 6A7 tube. The cathode of the 6A7 tube connects to ground.

Next we come to the component labelled T_4. This is the symbol for an air core transformer. Actually, inside the shield can, as indicated by the dotted line, there are two separate transformers. The top section consists of L_5 and L_7, and the bottom section consists of L_6 and L_8. C_{11} is a variable condenser connected between the bottom end of L_5 and ground. C_{26} is a fixed condenser which is connected between the bottom of L_6 and ground.

Let us skip over the remainder of the diagram and identify some parts at random.

The 6D6 is a pentode type tube. It has a heater, cathode, three grids and a plate.

The 75 tube is a dual purpose tube. It has a triode section and two diodes. The grid connection comes into the top of this tube. The lead connecting the grid of the 75 tube to condenser C_{22} is a shielded wire. Condenser C_{22} connect to the arm of a variable resistor R_5. R_5 is a potentiometer. In this circuit it is used for a volume control.

The transformer T_2 is an iron core transformer. Its primary is connected to the plate of the type 41 tube. A loud-speaker is connected to the secondary of T_2.

Now skipping to the bottom of our diagram we find a power transformer T_1. This transformer has one primary winding and three secondary windings. One of the secondary windings is center-tapped. The ends of this center-tapped winding connect to the plates of a double diode, type 80, tube. The center-tap of this winding connects to an iron core coil, or choke, L_{11}. The other end of L_{11} connects to ground. The symbol P_1 is a non-standard symbol for a pilot or dial light.

The primary winding of T_1 connects to the a-c line through a single pole single throw switch, S_4. Condenser C_{20}, a .01 mfd (microfarad) condenser, connects from one side of T_1 primary winding to ground.

In this manner, continue over the entire schematic diagram, identifying *each* part until you can do it without referring back to the symbols in this assignment.

Tracing a Circuit

Although, at this point in our training, we have not studied the operation of the various circuits in a radio, we should be able to trace some of the circuits in a schematic diagram.

For the purpose of practice in tracing a circuit, the schematic diagram of the receiver, shown in Figure 1, will be used. This is a relatively simple circuit, being conventional in every respect. Complete radios of this type can be broken down into a number of separate circuits, which allows easier tracing of the wiring.

First, let us trace the filament or heater circuits, since we should now be able to recognize this element of each tube. Notice that in this radio one terminal of the heater of each tube (except the type 80 rectifier) is grounded and the other terminal of each heater has an arrowhead. In this case the ground symbol represents the metal chassis. It does not, however, necessarily mean that each tube has one of its heater terminals grounded at the tube socket, nor does it mean that the chassis acts as part of the filament circuit. It merely means that at some point in the actual wire circuit one side of the filament is connected to the chassis.

In these schematic diagrams you may often have to visualize a complete circuit when a part of this circuit is shown making use of the metal chassis as one of the conductors. Notice that the two green terminals of one of the secondary windings of the power transformer are arranged the same way - that is, one terminal is grounded and the other terminal has an arrowhead.

The reason the draftsman did not use actual lines to show these connections is that this would require that there be more lines on the diagram - making it more confusing. This is an example of the short cuts often used in radio diagrams. We have redrawn this filament circuit as it is actually wired in Figure 12.

Let us compare the schematic diagram shown in Figure 12 with that section of the complete schematic in Figure 1. First examine the heater circuit of the 6A7 tube. Remember that any points connected to ground are connected together electrically. Therefore the terminal of the heater which is shown grounded is connected electrically to one terminal of the secondary winding of the transformer as shown in Figure 12. The other terminal of the 6A7 heater has an arrowhead on it. This indicates that it connects to the transformer terminal with the arrowhead. Thus we see that this tube is actually wired as shown in Figure 12. Check the other tubes heater circuits to see if they agree with Figure 12. Notice that the filament circuit of the type 80 tube connects directly to another secondary winding on the power transformer.

Continuing with our tracing of the circuit of Figure 1, in the order of simplicity, the plate circuits are next. From the plate of the first tube from the left, the 6A7, follow the wire to the primary of the tuned transformer, T_5. Notice that the condenser C_6 is connected across each end of the primary, serving to tune it to the proper frequency. Going on through the primary, we can follow this wire to a point where it connects to another wire. This junction is marked A on our diagram. Now start from the plate of the second tube from the left, the 6D6, and we see that we go through the primary of another tuned transformer, T_6, to the junction of the wire from the plate of the first tube. The wire from junction A continues to a horizontal line leading to the right from the filament of the type 80 tube. Keep this horizontal line in mind - it is known as the "B+ feeder line". Now go to tube number three, a type 75, and follow the lead from the plate of the triode section of this tube (the plate at the top of the symbol) through a resistor R_9, which has a value of 330 K or 330,000 ohms, to the B+ feeder line. In tracing such circuits you may come to a junction leading to a condenser; we will ignore this branch now because at this time we are tracing d-c circuits, and as we shall learn later, condensers will not pass direct current. The plate of the audio amplifier tube, a type 41, also connects to this B+ feeder line through the primary of transformer T_2. This completes the tracing of all the plate circuits in our receiver, except the type 80 tube. If we had been drawing this circuit as we traced it, our drawing should look like Figure 13.

Almost without exception, the plate of every tube in a receiver connects through coils, resistors or both to the filament or cathode of the rectifier tube (in this case, the type 80 tube).

Thus we find that it is not a difficult task to trace the individual circuits in a piece of radio or television equipment.

Summary

We have covered a great deal of ground in this assignment and we are already well along the way to being a competent electronics and television technician. We have seen the need for schematic diagrams, we have studied the symbols for many of the components which make up electronics and television circuits, and we have seen how these symbols are put together to make complete diagrams. We have also learned how to trace out individual circuits of a complete diagram.

This is very necessary to enable us to quickly and efficiently work on such a piece of equipment and understand how these various circuits operate. You should refer to this assignment time and time again in your studies, and you should practice tracing circuits until it comes to you very easily. Do not be discouraged, for with practice this assignment will seem quite easy to you a month from now.

In the next assignment we will review some of the arithmetic that we will use in our electronics and television work. For most of us, this will amount to just a simple, quick review.

Test Questions

Be sure to number your Answer Sheet Assignment 3.
Place your Name and Associate Number on *every* Answer sheet.
Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. Why are schematic diagrams used?

2. How, or where, could you obtain the schematic diagram for a radio you have been called upon to repair?

3. On your Answer Sheet, draw and label the symbols for the following electronics parts:
   (a) fixed resistor (c) potentiometer
   (b) variable condenser (d) electrolytic condenser

4. On your answer sheet draw the symbol for an iron core transformer with one center tapped secondary winding. Connect the two ends of a potentiometer to the two ends of the secondary winding. Connect the "arm" of the potentiometer to the center-tap of the secondary winding.

5. What is another name for a condenser? capacitor

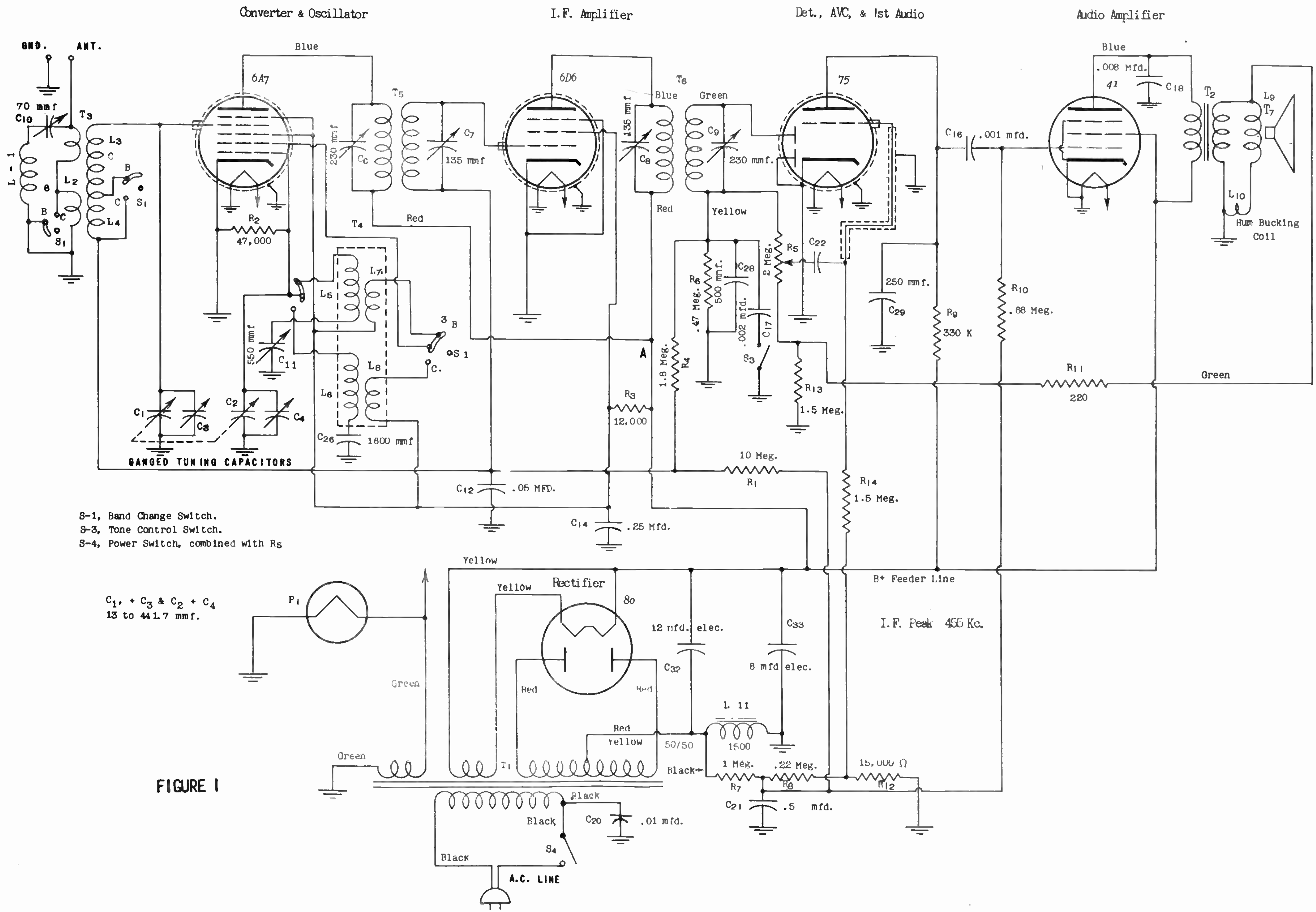
6. Draw the symbols for the following:
   (a) Fuse (c) Pilot light
   (b) Antenna (d) Single pole single throw switch

7. Draw the symbols for the following:
   (a) Air Core transformer (c) 30 volt battery
   (b) Power transformer (d) Triode vacuum tube

8. What do the straight lines in the power transformer symbol indicate?

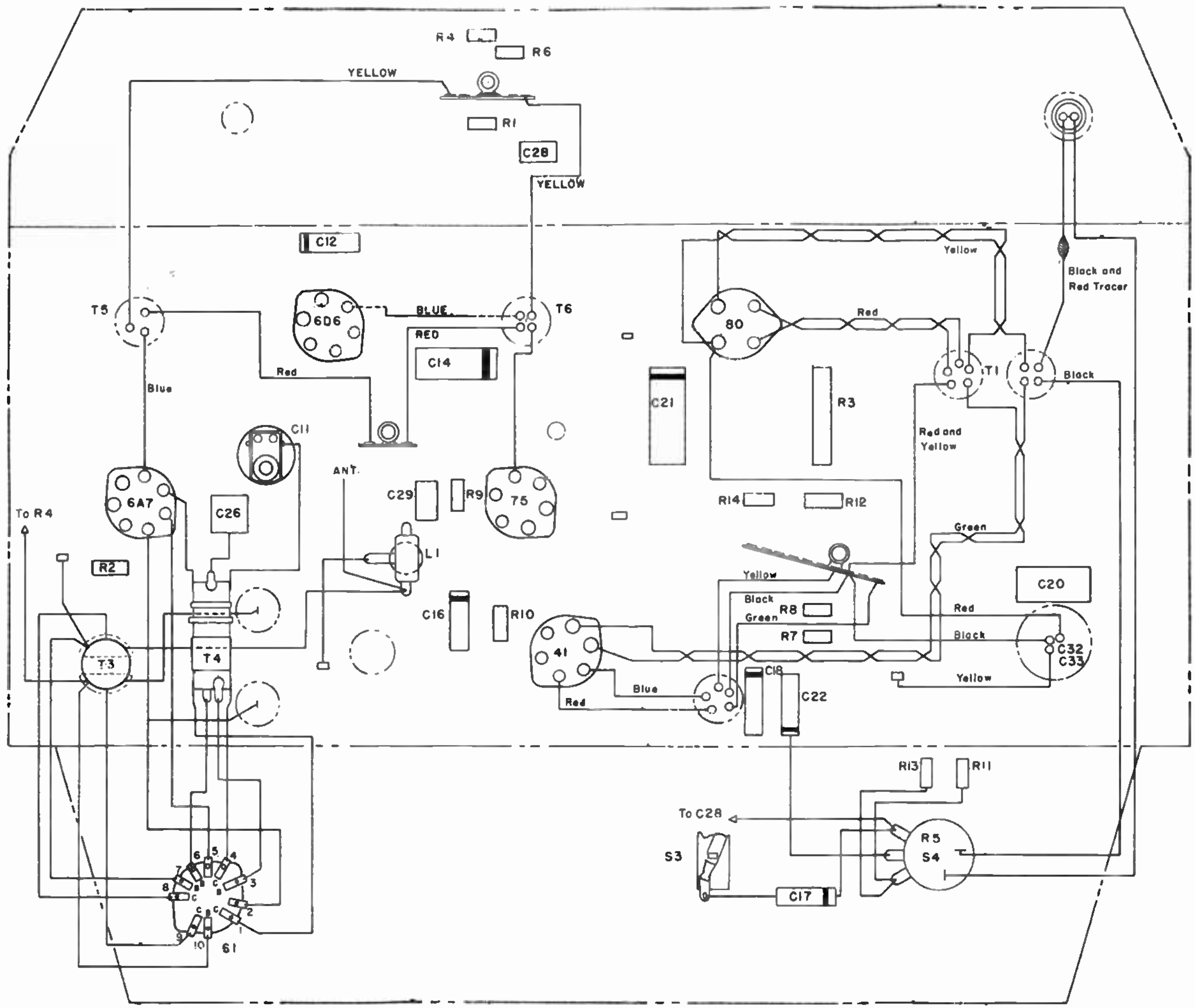
9. In Figure 1 of this assignment, what does the dotted circle around the type 75 tube indicate?

10. Draw the symbols for the following:
    (a) Loudspeaker (c) Two gang variable condenser
    (b) Headphones (d) Microphone



Converter & Oscillator
I.F. Amplifier
Det., AVC, & 1st Audio
Audio Amplifier
GND.
ANT.
Blue
6A7
6D6
75
41
70 mmf
C10
T3
L-1
L2
L3
L4
S1
T5
230 mmf
C6
C7
135 mmf
T4
Red
R2
47,000
L5
L7
L8
L6
3
B
S 1
C.
550 mmf
C11
C1
C3
C2
C4
GANGED TUNING CAPACITORS
C26
1600 mmf
T6
Blue
Green
135 mmf
C8
C9
230 mmf.
Red
Yellow
A
R3
12,000
R6
.47 Meg.
500 mmf.
C28
.002 mfd.
C17
S3
2 Meg.
R5
C22
R4
1.8 Meg.
R13
1.5 Meg.
250 mmf.
C29
R9
330 K
C16
.001 mfd.
R10
.68 Meg.
R11
220
Green
.008 Mfd.
C18
T2
L9
T7
L10
Hum Bucking Coil
10 Meg.
R1
R14
1.5 Meg.
C12
.05 MFD.
C14
.25 Mfd.
S-1, Band Change Switch.
S-3, Tone Control Switch.
S-4, Power Switch, combined with R5
C1, + C3 & C2 + C4
13 to 441.7 mmf.
P1
Yellow
Rectifier
80
12 mfd. elec.
C32
C33
8 mfd elec.
B+ Feeder Line
I.F. Peak 455 Kc.
Green
Red
L 11
1500
50/50
Black
1 Meg.
R7
.22 Meg.
R8
15,000 Ω
R12
C21
.5 mfd.
T1
Black
C20
.01 mfd.
S4
A.C. LINE

FIGURE I



CHASSIS PARTS LAYOUT

FIGURE NO.2

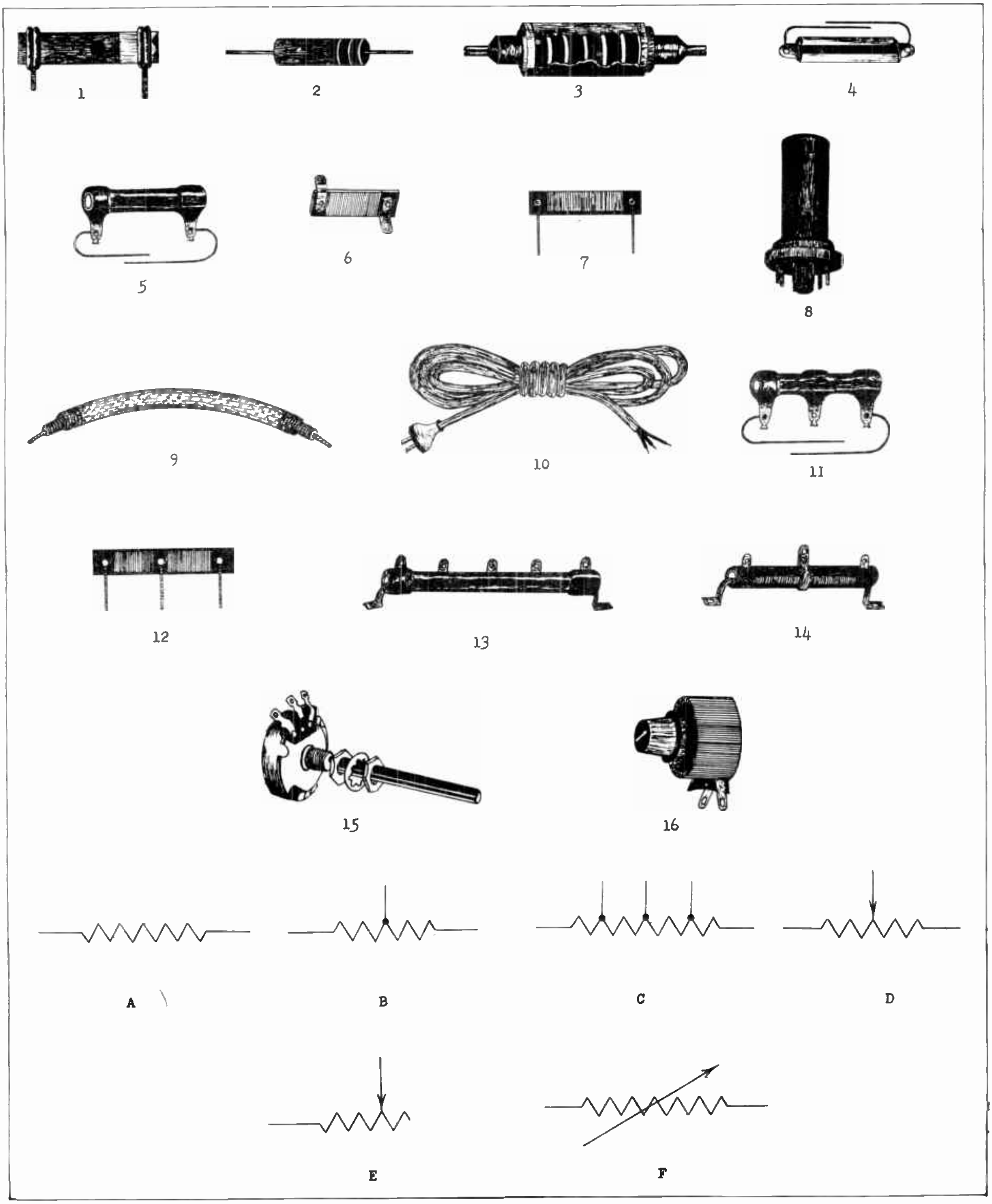


FIGURE 3

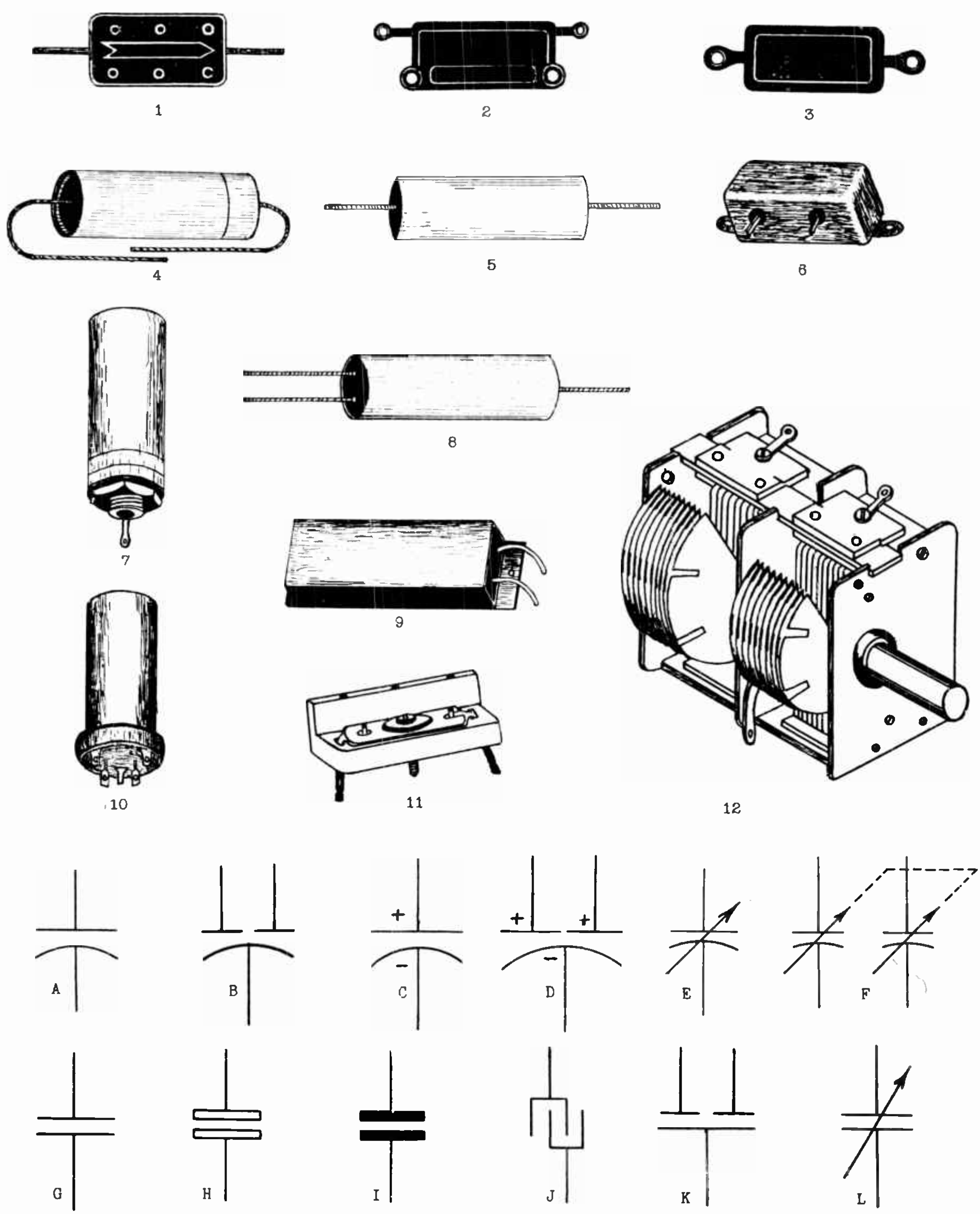


FIGURE 4

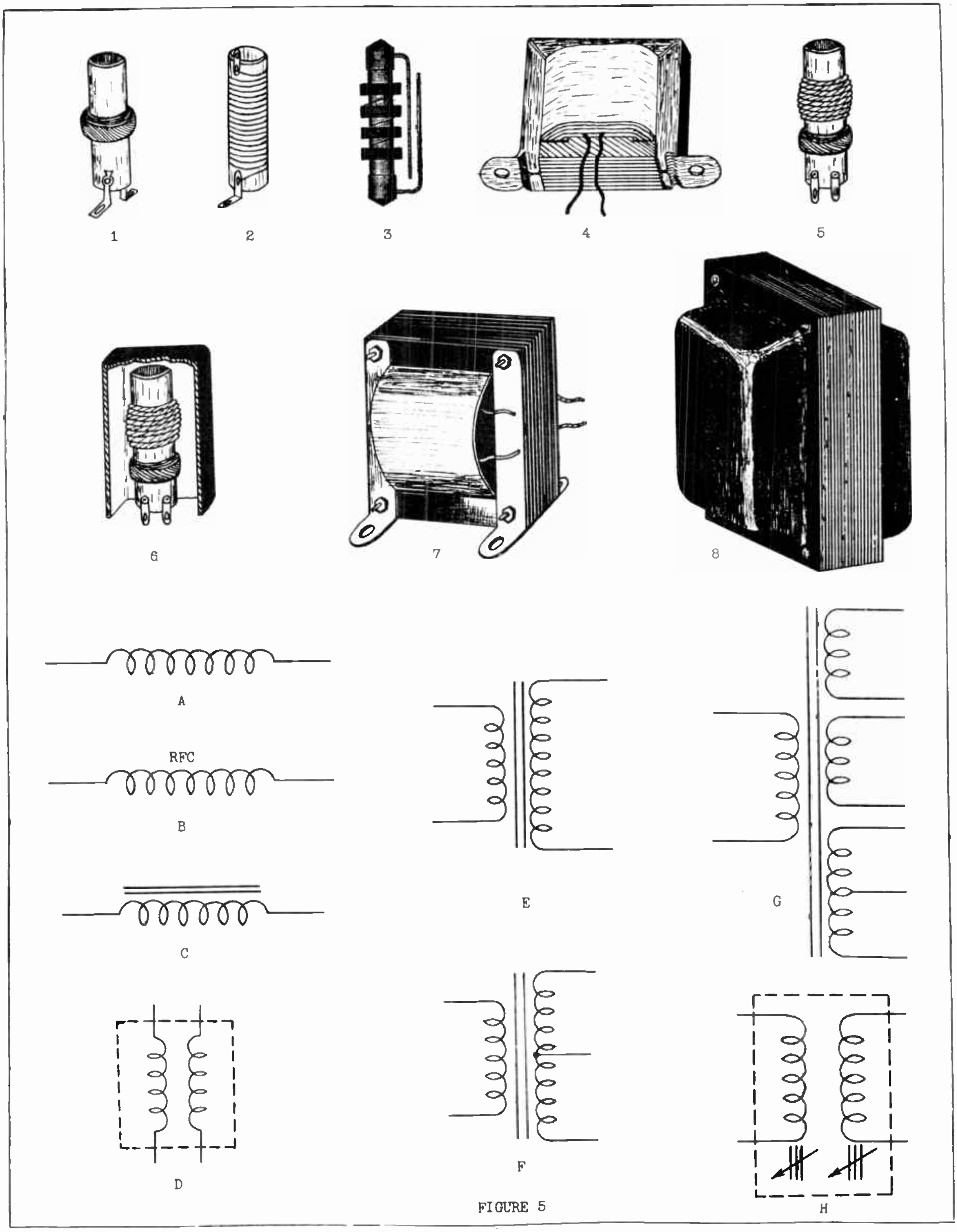


FIGURE 5

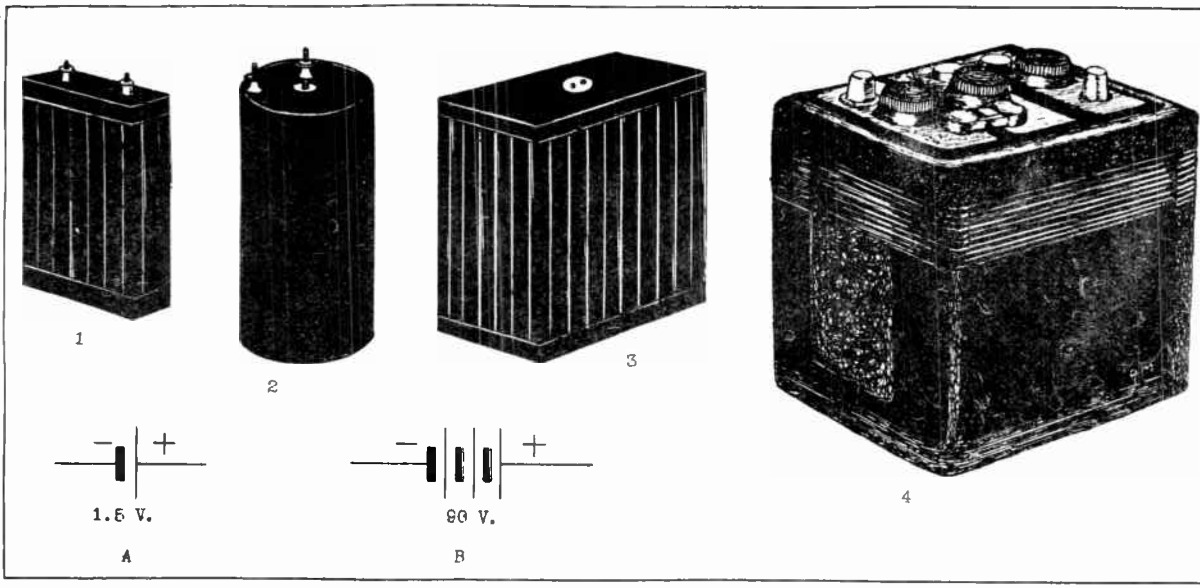


FIGURE 6

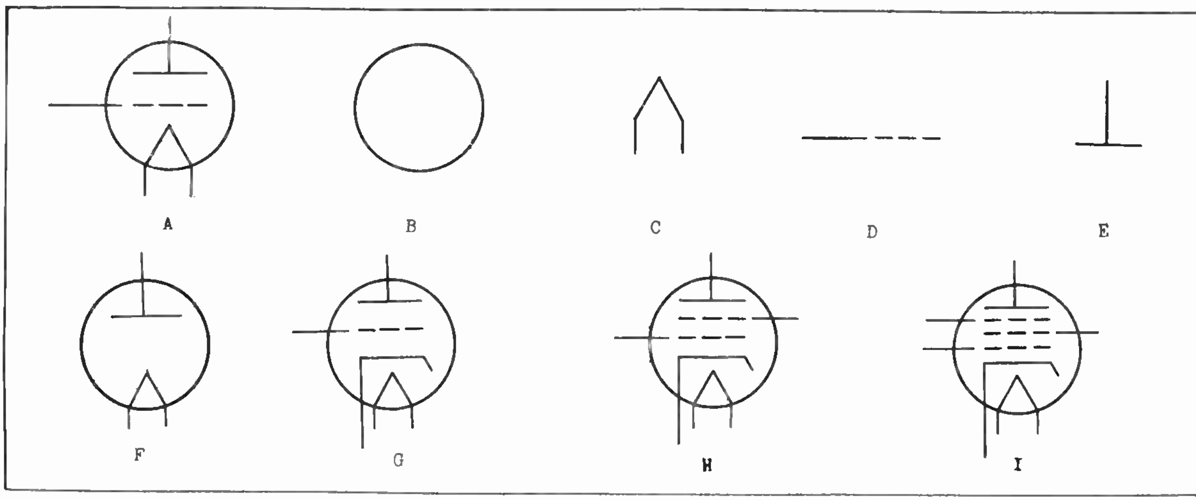


FIGURE 7

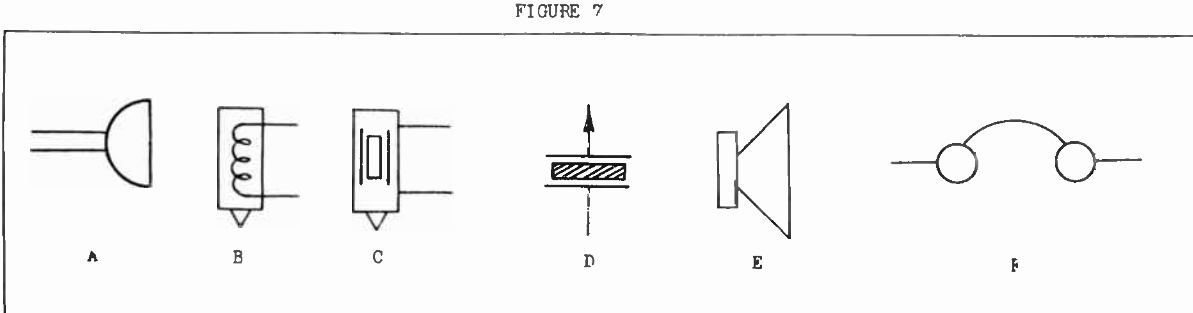


FIGURE 8

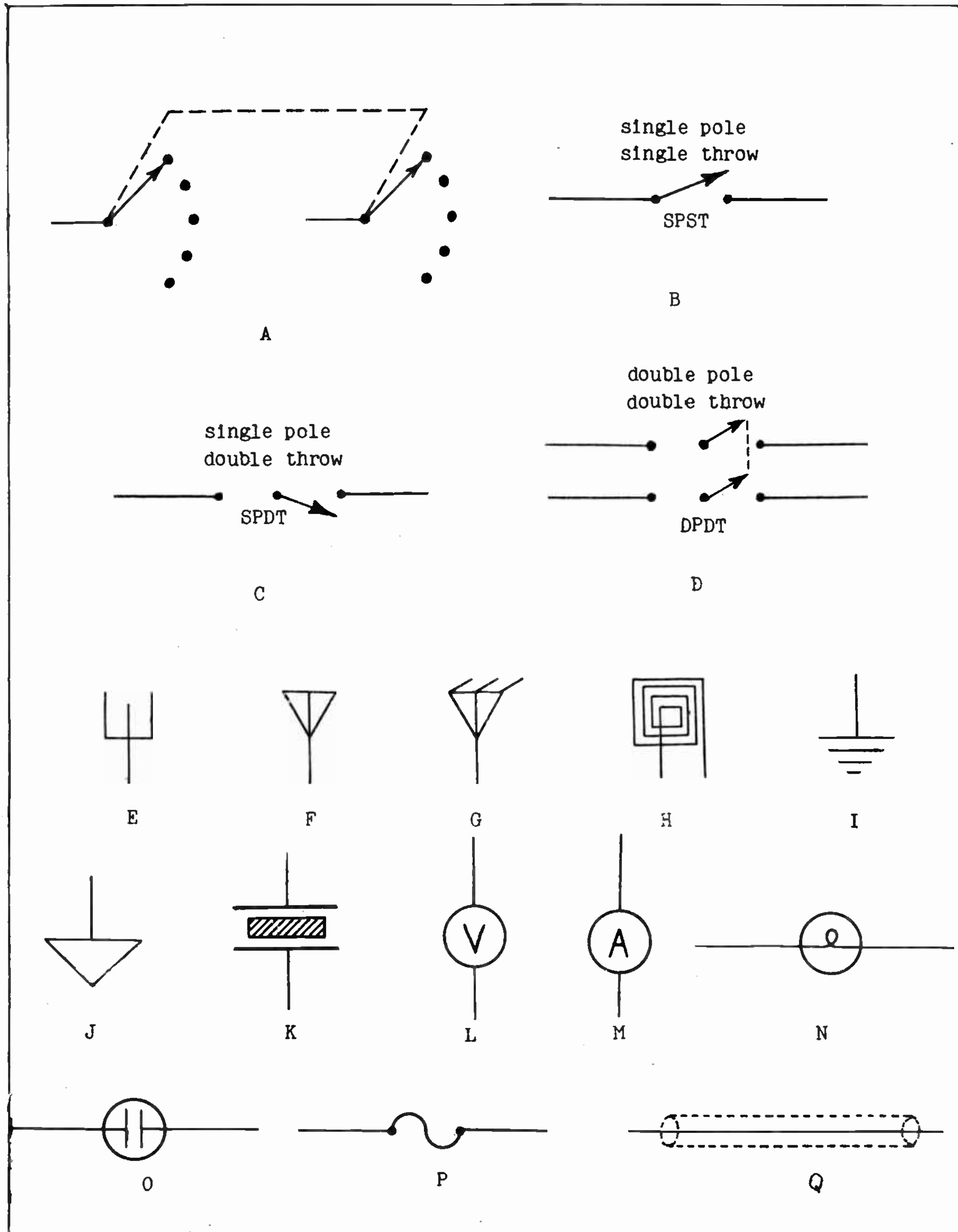

single pole
single throw
SPST
A
B
single pole
double throw
SPDT
double pole
double throw
DPDT
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q

FIGURE 9

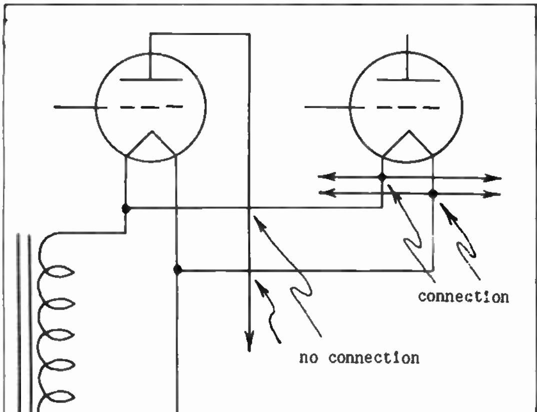


FIGURE 10

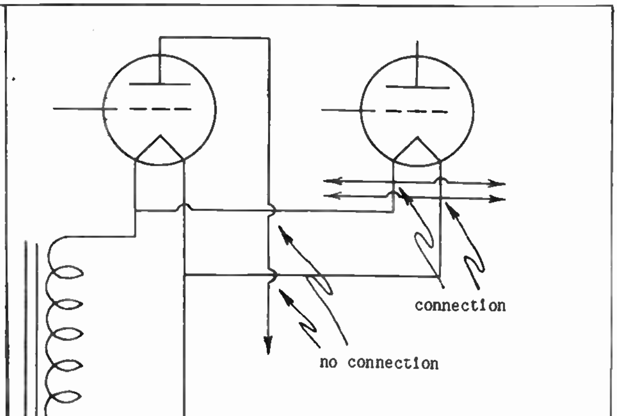


FIGURE 11

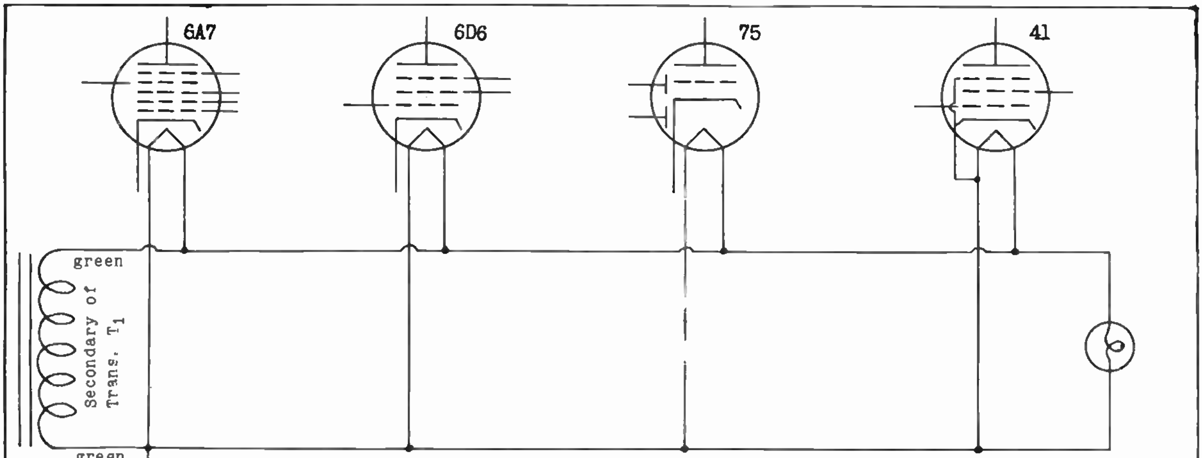


FIGURE 12

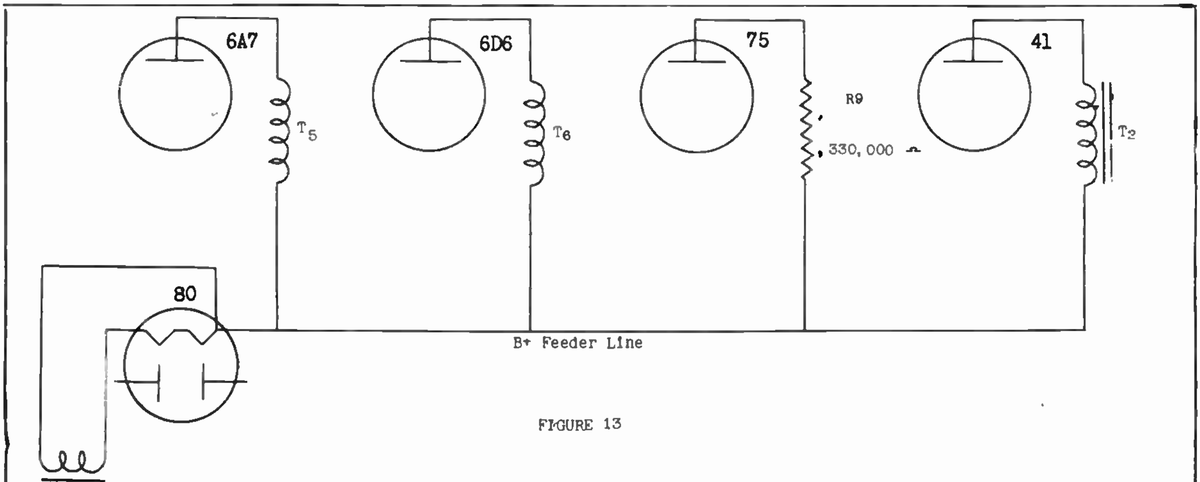


FIGURE 13

Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

ARITHMETIC FOR ELECTRONICS **ASSIGNMENT 4**

ASSIGNMENT 4

ARITHMETIC FOR ELECTRONICS

In our electronic and television work, problems will be encountered which will require the use of mathematics. In this assignment, and in a few others spaced throughout the training, all of the mathematics which will be needed to solve these problems and to become a competent electronics technician will be covered.

There is one point which we wish to emphasize at this time. The mathematics which is included in this training program should offer no particular difficulty to you. We will assume that you know only the very basic operations of arithmetic - addition, subtraction, multiplication, and division. Each operation will be started at this most basic point and explained thoroughly from there on.

We will show you simple methods of solving problems - in other words, we will show you the easy way to do the job by applying short cuts, etc.

Before we get into the actual subject of mathematics, there are a few words of advice that might be of great value to you. For one thing, you should get in the habit of doing your work neatly, carefully, and accurately, in order to reduce the possibility of careless mistakes. Even if you know what you're doing - know the mathematical operation and know the electronics work to which you are applying it - your answer may be worthless if you make a careless mistake in arithmetic.

None of us is perfect. We all stand a chance of making a mistake in arithmetic in even the most simple problems - even when we do the work neatly and carefully. We suggest, therefore, that you develop the habit of checking every bit of your work before you accept your answer as being correct.

When you start your work on the first Home Laboratory Experiment in the training program, you may find the operation of soldering rather awkward. However, as you proceed in the training and thereby have the opportunity of practicing soldering as you perform the many experiments, you'll soon find that it is a very simple operation. becoming "second nature" to you. You will find that, to a great extent, the same thing is true regarding mathematics. When you first start to use a particular operation in mathematics, you may find your handling of it a little awkward. However, as you acquire *practice* in its use, you will find that you'll also become efficient in its use.

You have, of course, found this to be true in the past, both in your own experience and in the experience of others. For example, multiplication is a short cut for addition, but you had to learn multiplication tables (through practice) before the multiplication process became useful to you. The typist finds it easier to prepare a page with a typewriter than with a pen or pencil yet considerable *practice* was necessary before the typewriter became a useful tool to her. Many short cuts will be presented in connection with the mathematics in this training. Practice in their use will enable you to arrive at a simple solution to electronics problems which would be difficult without mathematics.

This advice, then, might be summed up as follows:

Do your work neatly and carefully.
Practice.

Definitions

In this assignment, we will deal with addition, subtraction, multiplication, and division, and we will use whole numbers, fractions, mixed numbers, and decimals. Of course, the operations of addition, subtraction, multiplication, and division are so well known to everyone as to not require any definition. However, as it may have been a number of years since you "met" the various types of numbers we will use in this assignment, it might be well for us to "reintroduce" these numbers to you. In other words, we will give you definitions of them.

Whole Number. A whole number is a number which contains *no* fractions or decimals. Examples of whole numbers are: 1, 2, 13, 99, 796,843, etc.

Fraction. A fraction is one number over another, and is actually an indication of division. For example, 1/2 is a fraction and means divide 1 by 2. Some more examples of fractions are: 2/3, 4/5, 3/10, 99/1000, etc.

Mixed Number. A mixed number is a whole number and a fraction. For example: 1 1/2, 3 7/8, 99 47/100, etc.

Decimal. A decimal is another way of expressing a fraction. For example, the fraction 1/10 may be expressed as the decimal .1. Other examples are: .7, .99, .76543, etc.

Simple Arithmetic

Simple arithmetic, involving the processes of addition, subtraction, multiplication and division of whole numbers, is used each day in our everyday life and is familiar to all. Examples of each process will be given here as a foundation for other arithmetic.

Addition

Example 1. Add these numbers:

4732, 21, 492

```
Solution:  4732
             21
            492
           ----
Answer:    5245
```

Example 2. Add these numbers:

976, 74, 3986, 10

```
Solution:   976
             74
           3986
             10
           ----
Answer:    5046
```

For practice, work the following problems:

1. 721 + 432 =
2. 821 + 32 + 4312 + 8 =
3. 976 + 73 + 99 + 127 =
4. 7932 + 9732 + 2379 + 3792 =

Subtraction

Example 1. From 5245, subtract 492.

```
Solution:  5245     Check:  4753
           -492             +492
           ----             ----
Answer:    4753             5245
```

Example 2. From 99,876, subtract 11.

```
Solution:  99,876     Check:  99,865
              -11                +11
           ------             ------
Answer:    99,865             99,876
```

All subtraction problems should be "checked" by adding the answer obtained to the amount subtracted, and checking to see if the original number is obtained. Thus, in Example 1, 4753 should be added to 492, as shown at the right of the solution of the problem. Since the answer to the check, 5245 in this example, is equal to the original number, we know that the subtraction is correct. The check for Example 2 is also shown. For practice, work and check the following problems:

1. 7852 − 623 =
2. 491 − 287 =
3. 688 − 400 =
4. 9763 − 27 =

Multiplication

Example 1. Multiply 77 by 61.

```
Solution:    77                                77
            x61                  Check:  61 ⟌4697
             77                              427
            462                               427
Answer:    4697                               427
                                                0
```

Example 2. Multiply 4753 by 492.

```
Solution:   4753                                4753
            x492                 Check:   492 ⟌2338476
            9506                              1968
           42777                               3704
          19012                                3444
Answer:   2338476                               2607
                                                2460
                                                 1476
                                                 1476
                                                    0
```

Each multiplication problem should be checked by dividing the answer obtained by one of the numbers originally multiplied together. If the other original number is obtained as the answer to this check, the multiplication is correct. Thus, in the check for Example 1, the answer 4697, is divided by 61, and 77 is obtained. Since 77 is the number in the example which was multiplied by 61, the multiplication is correct. If any other number, such as 76, or $77\frac{13}{61}$ etc., is obtained, it indicates that there is a mistake in the arithmetic. The check for Example 2 is also shown. For practice, work and check the following problems:

1. 421 x 78 =
2. 9770 x 420 =
3. 623 x 796 =
4. 977 x 23,784 =

Division

Example 1. Divide 99 by 11.

```
Solution:        9 (Answer)
           11 ⟌99                Check:   11
                99                        x9
                 0                        99
```

Example 2. Divide 26,677 by 721.

```
Solution:         37 (Answer)
          721 ⟌26677             Check:   721
               2163                       x37
                5047                     5047
                5047                    2163
                   0                    26677
```

Example 3. Divide 784 by 53.

```
Solution:        14
            53 ⟌784
                53
                254
                212
Remainder:       42
```

We have a remainder of 42. The answer may be written as 14 + 42/53 or 14 42/53. The remainder is expressed as a *fraction*, 42/53.

The entire answer, 14 42/53, is a *mixed* number, because it contains a whole number and a fraction.

All division problems should be checked by multiplying the answer by the divisor (the part *divided by* in the problem). If the dividend (the part *to be divided* in the problem) is obtained from this multiplication in the check, the arithmetic is correct. In the check for Example 1, the answer 9 is multiplied by the divisor 11, and 99 is obtained. Since 99 is the dividend in the problem, the arithmetic is correct. The check for Example 2 is also shown.

To check a division problem where the answer is a mixed number, as in Example 3, we simply multiply the whole number of the answer by the divisor, then *add* the remainder. If the dividend is obtained from this operation, the arithmetic is correct. To check Example 3 we do the following:

```
  53  (divisor)
x 14  (whole number in answer)
 212
 53
 742
+ 42  (Remainder)
 784
```

Since 784 is the dividend, the arithmetic is correct.

In simple arithmetic it is usually best to express fractions as decimals. However, you will have to manipulate fractions when you work with radio formulas later on. The best way to review the rules for using fractions is to practice with problems in simple arithmetic.

A fraction is made up of two quantities, a top number, or *numerator*, and a bottom number, or *denominator*. In the fraction 42/53 42 is the numerator and 53 is denominator. The answer to the division problem, Example 3, tells us we have 14 whole numbers plus a fraction. The answer is between 14 and 15. If we take one and divide it into 53 parts and take 42 of these 53 parts, we will have the correct amount to add to the 14.

The denominator tells us into how many parts we have divided the whole unit. The numerator tells us how many of these parts we have taken.

It will often be necessary to combine fractions. Addition and subtraction are opposite and the same general rules will apply for either operation.

Addition and Subtraction of Fractions

Example 1. Add 3/8 and 2/8.
Answer: 3/8 + 2/8 = 5/8.

Example 2. Add 5/13 and 6/13.
Answer: 5/13 + 6/13 = 11/13.

Example 3. Subtract 2/8 from 3/8.
Answer: 3/8 - 2/8 = 1/8.

Example 4. From 6/13 subtract 2/13.
Answer: 6/13 - 2/13 = 4/13.

In each of these examples the denominators were the same for both fractions. We used that same denominator in our answer. The numerators in the answers were obtained by adding or subtracting (as instructed in the problem) the numerators of the two fractions.

This is a very simple process if both of the fractions have the same denominator. If the fractions do not have the same denominator, we will have to change one or more of the fractions in the problem to obtain a *common denominator. Common denominator* means that all of the fractions have the same *denominator.*

If we were asked to add 5/8 and 1/8 it could be done simply by the process outlined above, but if we were asked to add 1/2 and 3/5 it could not be done by this process. We would have to find a *common denominator* first.

We can always obtain a common denominator by multiplying the two denominators together. Thus, to find a common denominator in the problem 1/2 + 3/5 we multiply 2 x 5 and obtain 10. Thus, 10 is the common denominator. We now want each of our fractions to have 10 for a denominator. We want to change 1/2 into an unknown number of tenths. This we can do easily. We had to multiply the denominator 2 of the first fraction by 5 to get 10. We must multiply the numerator by 5 also. Thus, to change 1/2 to tenths, we multiply both the numerator and the denominator by 5. This gives us 5/10. To convert 3/5 to tenths we multiply both the numerator and the denominator by 2. This gives us 6/10. Now to solve the problem, we apply the same rule as in Example 1 and 2 since both of the fractions now have the same denominator. This is shown in Example 5.

Example 5. Add 1/2 and 3/5.
1/2 + 3/5 =
5/10 + 6/10 = 11/10

Example 6. Add 1/3 and 1/4.
1/3 + 1/4 =
4/12 + 3/12 = 7/12
Note: 12 will be a common denominator.

Example 7. Subtract 2/3 from 7/8.
7/8 - 2/3 =
21/24 - 16/24 = 5/24
Note: 24 will be a common denominator.

Example 8. Subtract 1/8 from 1/7.
1/7 - 1/8 =
8/56 - 7/56 = 1/56
Note: 56 will be a common denominator.

In each of these examples, we obtained the common denominator by multiplying the denominator of each of the fractions together. Sometimes it is possible to use a common denominator that is smaller than the product of the denominators in the problem.

Example 9. Add 1/6 and 3/8.
1/6 + 3/8 =
Using 48 as the common denominator;
8/48 + 18/48 = 26/48

In this case we could use 24 as the common denominator of the problem. Then to solve this same problem we proceed as follows:

1/6 + 3/8 =
Using 24 as the common denominator;
4/24 + 9/24 = 13/24

13/24 is equal to 26/48, so we have solved the problem and used smaller numbers than before.

You may wonder where the 24 was obtained as the common denominator in the preceeding example. It is the smallest number into which the 8 and the 6 can each be divided into evenly. In a great majority of the cases this number can be found by inspection. Another way the lowest common denominator can be found is shown by Example 10.

Example 10. Add 5/8, 7/12, and 11/18.

To find the lowest common denominator (abbreviated LCD), we proceed as follows:

(1)	2	8,	12,	18
(2)	2	4,	6,	9
(3)	2	2,	3,	9
(4)	3	1,	3,	9
(5)	3	1,	1,	3
		1,	1,	1

Explanation: To obtain the LCD of these numbers, write their denominators, 8, 12, and 18 in a line as shown and divide by the smallest number that will go into one or more of the numbers without a remainder. Thus, 2 will go into 8 four times, into 12 six times and into 18 nine times. Write the 4 under the 8, 6 under the 12 and 9 under the 18 as shown in line (2). We now divide each of these numbers in line (2) by 2, and where one of these numbers in the lines can not be divided evenly by the divisor, we bring down the number itself. Thus 2 goes into 4 twice, so we put the 2 under the 4. The number 2 goes into 6 three times, so we put the 3 under the 6, but since the 2 does not go into the 9 evenly, we bring down the 9. In this way we obtain line (3). Dividing the numbers in line (3), by 2 we obtain for line (4), 1, 3, 9. Dividing line (4) by 3, we obtain 1, 1, 3, for line (5). Again dividing by 3, we obtain 1, 1, 1, for line (6). Now we obtain the lowest common denominator by multiplying the divisors together. In this case, 2 x 2 x 2 x 3 x 3 = 72. Therefore, 72 is the lowest common denominator of these fractions. We then use the LCD to find the solution to the example. Therefore:

5/8 + 7/12 + 11/18 =

45/72 + 42/72 + 44/72 = 131/72

To apply this same method to solve Example 9, we proceed as follows:

1/6 + 3/8 =

2	6,	8
2	3,	4
2	3,	2
3	3,	1
	1,	1

LCD 2 x 2 x 2 x 3 = 24

This is how the common denominator of 24 was obtained in Example 9.

In all cases, notice that when we changed to common denominators, we multiplied *both* the denominator and numerator by the *same* number. This is always necessary in order that we do not change the value of our fraction.

For practice, work the following problems:

1. 5/8 + 3/8 =
2. 9/16 + 3/16 =
3. 1/8 + 1/5 =
4. 3/5 - 1/6 =
5. 7/8 + 1/6 + 1/3 =
6. 9/16 + 7/24 + 7/32 =
7. 13/18 - 7/27 =
8. 1/3 + 1/4 + 1/5 + 1/6 =

Multiplication and Division of Fractions

Multiplication and Division of fractions is much easier than addition and subtraction for two reasons. In the first place, we *do not* have to bother with common denominators. In the second place, we find we can often reduce the size of the numbers we are working with, by means of *cancellation*.

In multiplication of fractions, we multiply all the numerators together to obtain the numerator of the answer, and we multiply all of the denominators together to obtain the denominator in the answer.

Example 1. Multiply 2/7 by 3/5.

Solution: 2/7 x 3/5 = 6/35

The two numerators, 2 and 3, are multiplied together to obtain the numerator (6) of the answer. The two denominators, 7 and 5, are multiplied together to obtain 35 for the denominator of the answer.

Example 2. Multiply 3/7 by 6/7.

Solution: 3/7 x 6/7 = 18/49

Example 3. Multiply together, 1/2, 2/3, and 3/4.

Solution: $1/2 \times 2/3 \times 3/4 = \frac{1 \times 2 \times 3}{2 \times 3 \times 4} = \frac{6}{24}$

Example 4. Multiply these fractions together, 3/8, 1/3, and 5/9.

Solution: $3/8 \times 1/3 \times 5/9 = \frac{3 \times 1 \times 5}{8 \times 3 \times 9} = \frac{15}{216}$

For practice, work the following problems:

1. 3/4 x 3/4 =
2. 7/8 x 19/16 =
3. 5/12 x 1/9 =
4. 3/4 x 5/6 x 11/12 =

Division of fractions is also a simple process. To do this we invert the divisor (turn it upside down) and change the division sign to a multiplication sign, and then multiply the fractions.

Example 5. Divide 1/2 by 1/4.

Solution: 1/2 ÷ 1/4 =
1/2 x 4/1 = 4/2

Note that we inverted the divisor (the 1/4 in this example), then we multiplied.

Example 6. Divide 2/3 by 3/4.

Solution: 2/3 ÷ 3/4 =
2/3 x 4/3 = 8/9

Example 7. Divide 7/12 by 5/8.

Solution: 7/12 ÷ 5/8 =
7/12 x 8/5 = 56/60

For practice, work the following problems:

1. 9/10 ÷ 3/4 =
2. 1/7 ÷ 5/8 =
3. 19/21 ÷ 21/37 =
4. 7/8 ÷ 2 =

Note: Any whole number such as 2 may be written as that number over 1, or in this case 2/1.

We mentioned previously that the multiplication and division of fractions could be simplified by using *cancellation*. Let us see how this is accomplished.

When we were finding the common denominator, we said that it was permissible to multiply both the numerator and the denominator of a fraction by the same number, and that this did not change the value of the fraction.

It is also permissible to divide *both* the numerator and denominator by the same number.

The following example will demonstrate this:

Example 1. 6/10 can be written $\frac{6 \div 2}{10 \div 2}$, now 6 ÷ 2 = 3, and 10 ÷ 2 = 5. The fraction is now 3/5 which is equal to 6/10. It is found simpler to do this by the process called cancellation. To employ cancellation, examine the fraction to see if there is some number which can be divided into *both* the *numerator* and the *denominator.* In this fraction, 6/10 we see that 2 can be divided into each. Then we proceed in this manner. Without bothering to write the 2 down, we say to ourself, 2 goes into 6 three times and into 10 five times. We then cross out, or *cancel*, the 6 and put a 3 above it, and *cancel* the 10 and put a 5 below it.

$$\begin{array}{c} 3 \\ \cancel{6} \\ \hline \cancel{10} \\ 5 \end{array}$$

The new fraction is 3/5.

We have reduced this fraction to its lowest terms. We can find no number which will go evenly into both 3 and 5.

Example 2. Reduce 12/60 to its lowest terms.

$$\begin{array}{c} 6 \\ \cancel{12} \\ \hline \cancel{60} \\ 30 \end{array}$$

Here we divided by 2. This fraction is still not in its lowest terms, for we can still divide 2 into each of the terms. Let us do this.

$$\begin{array}{c} 3 \\ \cancel{6} \\ \hline \cancel{30} \\ 15 \end{array}$$

Now we have 3/15, but this fraction is not in its lowest terms since 3 and 15 can both be divided by 3. Let us do this.

$$\begin{array}{c} 1 \\ \cancel{3} \\ \hline \cancel{15} \\ 5 \end{array}$$

We now have reduced this fraction to its lowest terms by cancellation.

$$\begin{array}{c} 1 \\ \cancel{3} \\ \cancel{6} \\ \cancel{12} \\ \hline \cancel{60} \\ \cancel{30} \\ \cancel{15} \\ 5 \end{array}$$

All of these steps would normally be performed without rewriting the fraction each time. This is shown at the left.

There is no set rule as to what number you should divide into both the numerator and the denominator. Fewer steps will result if the largest number possible is used. For example, in the fraction 12/60, if we had divided both parts by 12 in the first place, we would have had only one step. There are a number of ways that we could have arrived at this same answer. Some of these are illustrated below:

Dividing by 12.
$$\begin{array}{c} 1 \\ \cancel{12} \\ \hline \cancel{60} \\ 5 \end{array}$$

Dividing by 6 and then by 2.
$$\begin{array}{c} 1 \\ \cancel{2} \\ \cancel{12} \\ \hline \cancel{60} \\ \cancel{10} \\ 5 \end{array}$$

Dividing by 3 and then by 4.
$$\begin{array}{c} 1 \\ \cancel{4} \\ \cancel{12} \\ \hline \cancel{60} \\ \cancel{20} \\ 5 \end{array}$$

A fraction should always be reduced to its lowest terms to be in its proper form. If the answer to a problem contains a fraction, this fraction should be reduced to its lowest terms.

For practice, look back over the preceeding problems on fractions and reduce each answer to its lowest terms.

Cancellation *can* be used when multiplying fractions. In division of fractions, first invert the divisor and then cancel. *Cancellation cannot* be used in addition and subtraction of fractions.

Let us work a longer problem to show how much work can be saved by cancellation.

Example 1.

$\frac{625}{35} \times \frac{64}{40} \times \frac{49}{56}$ can be written as $\frac{625 \times 64 \times 49}{35 \times 40 \times 56}$

$$\frac{\overset{125}{\cancel{625}} \times \overset{8}{\cancel{64}} \times \overset{7}{\cancel{49}}}{\underset{7}{\cancel{35}} \times \underset{5}{\cancel{40}} \times \underset{8}{\cancel{56}}}$$

First: Cancel 5 into 625 and 35.

Cancel 8 into 64 and 40.

Cancel 7 into 49 and 56.

$$\frac{\overset{\overset{25}{\cancel{125}}}{\cancel{625}} \times \overset{\overset{1}{\cancel{8}}}{\cancel{64}} \times \overset{\overset{1}{\cancel{7}}}{\cancel{49}}}{\underset{\underset{1}{\cancel{7}}}{\cancel{35}} \times \underset{\underset{1}{\cancel{5}}}{\cancel{40}} \times \underset{\underset{1}{\cancel{8}}}{\cancel{56}}}$$

Next: Since we have an 8 in the numerator and the denominator, we will cancel 8 into each.

Cancel 7 into 7 and 7.

Cancel 5 into 125 and 5.

$\frac{25 \times 1 \times 1}{1 \times 1 \times 1} = \frac{25}{1} = 25$ (*answer*)

Naturally, in actual work it will not be necessary to rewrite your problem as you perform each step in cancellation.

The simplicity of this process will be further demonstrated by Examples 2, 3, 4, and 5.

Example 2. Multiply 15/16 x 4/5 x 2/3.

Solution: $\frac{15}{16} \times \frac{4}{5} \times \frac{2}{3} = \frac{15 \times 4 \times 2}{16 \times 5 \times 3}$

$$\frac{\overset{\overset{1}{\cancel{3}}}{\cancel{15}} \times \overset{1}{\cancel{4}} \times \overset{1}{\cancel{2}}}{\underset{\underset{2}{\cancel{4}}}{\cancel{16}} \times \underset{1}{\cancel{5}} \times \underset{1}{\cancel{3}}} = \frac{1}{2}$$

Cancel 4 into 4 and 16.

Cancel 5 into 15 and 5.

Cancel 3 into 3 and 3.

Cancel 2 into 2 and 4.

Example 3. Multiply $\frac{300}{500} \times \frac{7}{8} \times \frac{45}{63}$

Solution: $$\frac{\overset{3}{\cancel{300}} \times \overset{1}{\cancel{7}} \times \overset{\overset{1}{\cancel{5}}}{\cancel{45}}}{\underset{\underset{1}{\cancel{5}}}{\cancel{500}} \times 8 \times \underset{\underset{1}{\cancel{9}}}{\cancel{63}}} = \frac{3}{8}$$

Cancel 100 into 300 and 500.

Cancel 7 into 7 and 63.

Cancel 9 into 45 and 9.

Cancel 5 into 5 and 5

Example 4. Divide 4/25 by 2/5.

Solution: $\frac{4}{25} \div \frac{2}{5} = \frac{\not{4}^{2}}{\not{25}_{5}} \times \frac{\not{5}^{1}}{\not{2}_{1}} = \frac{2}{5}$

Example 5. Divide 750/54 by 25/9.

Solution: $\frac{750}{54} \div \frac{25}{9} = \frac{\not{750}^{\not{30}\,5}}{\not{54}_{\not{6}\,1}} \times \frac{\not{9}^{1}}{\not{25}_{1}} = 5$

For practice, work the following problems:

1. $\frac{9}{10} \times \frac{5}{3} =$

2. $\frac{650}{20} \times \frac{80}{15} \times \frac{75}{40} =$

3. $\frac{3}{4} \times \frac{96}{100} \times \frac{16}{27} =$

4. $\frac{77}{90} \div \frac{22}{60} =$

5. $\frac{96}{99} \times \frac{77}{27} \times \frac{18}{32} =$

Improper Fractions and Mixed Numbers

In some of the problems, we had fractions in which the numerator was larger than the denominator, $\frac{11}{10}$ for example. Such a fraction is called an improper fraction. When improper fractions appear in an answer, they should be changed to *mixed numbers*. We stated previously that a mixed number was a whole number and a fraction. The number $\frac{11}{10}$ should be changed to the mixed number $1\frac{1}{10}$. The value of the mixed number can be obtained readily by dividing the numerator by the denominator.

Example 1: Change 11/10 to a mixed number.

Solution:

$$\begin{array}{r} 1 \\ 10\overline{)11} \\ \underline{10} \\ 1 \end{array} = 1\frac{1}{10}$$

Other examples of changing improper fractions to mixed numbers follow.

Example 1. Change 17/2 to a mixed number.

Solution:

$$\begin{array}{r} 8 \\ 2\overline{)17} \\ \underline{16} \\ 1 \end{array} = 8\frac{1}{2}, \quad \frac{17}{2} = 8\frac{1}{2}$$

Example 2. Change 131/72 into a mixed number.

Solution: $72 \overline{)131}$, $\frac{131}{72} = 1\frac{59}{72}$

$$\begin{array}{r} 1 \\ 72\,\overline{)131} \\ 72 \\ \hline 59 \end{array}$$

Example 3. Change 413/22 to a mixed number.

Solution: $22\overline{)413}$, $\frac{413}{22} = 18\frac{17}{22}$

$$\begin{array}{r} 18 \\ 22\,\overline{)413} \\ 22 \\ \hline 193 \\ 176 \\ \hline 17 \end{array}$$

Mixed numbers *cannot* be used conveniently in solving problems involving multiplication and division, so if a mixed number appears in a problem, it should be changed to an improper fraction before proceeding.

Example 1. Multiply 1 1/3 times 1/4.

We wish to multiply the mixed number 1 1/3 by a fraction. First we change 1 1/3 to an improper fraction. The number, 1 1/3 means one plus one third, so let us write it that way.

$1 + \frac{1}{3}$ 1 may be written as $\frac{1}{1}$, so we may again re-write the mixed number.

$\frac{1}{1} + \frac{1}{3}$ Now we have a problem of adding two fractions so we combine them by using a common denominator, 3 in this case. The improper fraction is $\frac{4}{3}$ which is equal to $1\frac{1}{3}$. The problem may easily be solved now.

$\frac{3}{3} + \frac{1}{3} = \frac{4}{3}$

Solution to Example 1: $1\frac{1}{3} \times \frac{1}{4}$

$$\frac{4}{3} \times \frac{1}{4} = \frac{\cancel{4}^{1}}{\cancel{12}_{3}} = \frac{1}{3}$$

Example 2. Change 4 3/5 to an improper fraction.

$$4\frac{3}{5} = \frac{4}{1} + \frac{3}{5} = \frac{20}{5} + \frac{3}{5} = \frac{23}{5}$$

A simpler way to write this is:

$$4\frac{3}{5} = \frac{(4 \times 5) + 3}{5} = \frac{23}{5}$$

Example 3. Change 7 9/11 to an improper fraction.

$$7\frac{9}{11} = \frac{(7 \times 11) + 9}{11} = \frac{86}{11}$$

Example 4. Change 6 7/8 to an improper fraction.

$$6\frac{7}{8} = \frac{(6 \times 8) + 7}{8} = \frac{55}{8}$$

For practice, work the problems on the following page:

Change to mixed numbers.

1. $\frac{9}{7}$ 2. $\frac{99}{62}$ 3. $\frac{163}{23}$

Change to improper fractions.

1. $9\frac{1}{3}$ 2. $7\frac{6}{8}$ 3. $99\frac{1}{9}$

In multiplication and division involving mixed numbers, first change the mixed numbers to improper fractions.

Example 1. Multiply $3\frac{5}{8}$ by $7\frac{1}{9}$.

Solution: $3\frac{5}{8} \times 7\frac{1}{9}$

$$\frac{29}{\not{8}_1} \times \frac{\not{64}^8}{9} = \frac{232}{9} = 25\frac{7}{9}$$

Example 2. Divide $4\frac{3}{5}$ by $9\frac{2}{3}$.

Solution: $4\frac{3}{5} \div 9\frac{2}{3} = \frac{23}{5} \div \frac{29}{3} = \frac{23}{5} \times \frac{3}{29} = \frac{69}{145}$

In adding and subtracting mixed numbers, we can group all the whole numbers and then group all of the fractions. This is usually the easiest way to handle this type of problem.

Example 1. $37\frac{5}{8} + 4\frac{1}{2} - 18\frac{2}{3} =$

Solution: $37 + 4 - 18 = 23$, $\frac{5}{8} + \frac{1}{2} - \frac{2}{3} = \frac{15}{24} + \frac{12}{24} - \frac{16}{24} = \frac{11}{24}$

Final answer: $23 + \frac{11}{24} = 23\frac{11}{24}$

Example 2. $21\frac{1}{4} + 8\frac{1}{2} + 6\frac{2}{3} =$

Solution: $21 + 8 + 6 = 35$, $\frac{1}{4} + \frac{1}{2} + \frac{2}{3} = \frac{3}{12} + \frac{6}{12} + \frac{8}{12} = \frac{17}{12} = 1\frac{5}{12}$

Final Answer: $35 + 1\frac{5}{12} = 36\frac{5}{12}$

For practice, solve the following problems:

1. $1\frac{7}{8} \times 6\frac{1}{4} =$
2. $2\frac{1}{4} \div 1\frac{1}{3} =$
3. $16\frac{1}{5} + 17\frac{1}{3} + 3\frac{1}{10} =$
4. $6\frac{1}{4} \div 2\frac{3}{5} =$

Decimals

A *decimal fraction*, commonly called a decimal, is a fraction whose denominator is 10, 100, 1000, 10,000, etc. Thus 3/10, 95/100 and 625/1000 are all decimal fractions. Since the denominator of a decimal fraction is always 10 or some power of 10, that is, since it is always 1 followed by zeros, we write a decimal fraction more compactly by omitting the denominator entirely. Thus, 3/10 is written .3, 95/100 is written .95, and 625/1000 is written .625. To distinguish the decimal fraction .3 from the whole number 3, we place a period (.) in front of the number. This period is called the *decimal point*. Any number therefore, with a decimal point in front of it, is a fraction whose numerator is the number after the decimal point, and whose denominator is a 1 followed by as many zeros as there are figures in the number to the right of the point. Thus, .1 means 1/10, .75 means 75/100, and .2754321 means 2,754,321/10,000,000. The fraction 2/100 is expressed as a decimal as .02, 2/1000 as .002, and 2/10,000 as .0002.

The decimal fraction .3 is read three-tenths, .75 is read 75 hundredths, and .975 is read 975 thousandths etc.

For practice, state the following fractions as decimals:

1. $\frac{9}{10} =$ 3. $\frac{795}{1000} =$

2. $\frac{41}{100} =$ 4. $\frac{29,373}{100,000} =$

Let us suppose that you are fortunate enough to have the following money in your pocket: 3 one hundred dollar bills, 7 ten dollar bills, 4 one dollar bills, 8 dimes and 6 pennies. At a moments notice you could tell someone exactly how much money you have. Let us review the rules you would instinctively use in adding up the different amounts.

```
$300.
  70.
   4.
    .8
    .06
$374.86
```

In making the addition, every decimal point we used was kept in the same vertical column. This rule will always hold true for both *Addition* and *Subtraction* with decimal quantities. Also notice the position of each figure in the answer. The 3 is in the "hundreds place", the 7 is in the "tens place", and the 4 is in the ones or "units place". All these figures to the left of the decimal represent numbers of whole dollars. Those to the right of the decimal point represent decimal fractions of a dollar. The 8 (for 8 dimes) is in the "tenths place", and represents 8/10 of a dollar. The 6 is in the "hundredths place", and represents 6/100 of a dollar.

Addition and Subtraction of Decimals

Example 1. Add 963.3, 77.06, 90.234 and 17.4234.

Solution:
```
  963.3
   77.06
   90.234
   17.4234
 1148.0174
```
Answer: 1148.0174

Notice that the decimal points are arranged in a vertical column. The decimal point in the answer is in this same vertical column.

Example 2. Add 9.0006, 40.01, 777.777 and .000009.

Solution:
```
   9.0006
  40.01
 777.777
    .000009
 826.787609
```
Answer: 826.787609

Example 3. From 673.0909 subtract 423.762.

Solution:
```
  673.0909
 -423.7620
  249.3289
```

Notice that in this case we may add zeros to the right of the decimal since this is equivalent to multiplying both the numerator and denominator of the fraction by 10. The number 762/1000, is equal to 7620/10,000.

Example 4. From 9.09 subtract 4.1321.

```
Solution:   9.0900
           -4.1321
           -------
Answer:     4.9579
```

For practice, solve the following problems:

1. Add. 976.23, 7.707, 641.0302, .000007.
2. Add. 7432.001, 963.1, 724.0001, 91.69.
3. From 879.69 subtract 432.78.
4. From 900 subtract 899.9999.

Multiplication and Division of Decimals

Multiplication and division of decimals are performed in the same way as with whole numbers. The only difference is in locating the decimal point in the answer. The proper location of the decimal point is very important.

In multiplication, we locate the decimal point in the answer after we have performed the multiplication. We merely count up the number of digits, or places, we have to the right of the decimal place in the two numbers we are multiplying together, then place the decimal point that many places from the right in the answer.

```
Example 1.   432.1
               x.07
             ------
             30.247
```

There is one place to the right of the decimal place in 432.1 and there are two places to the right of the decimal place in .07. This makes a total of three places. After multiplying the numbers together, we count three places from right to left in the answer and locate the decimal place at that point.

```
Example 2.   7.204    Example 3.   .0007    Example 4.  6701    Example 5.  200.001
             x 2.1                 x .03                 x .7                x .0001
             -----                 -----               ------               --------
              7204               .000021               4690.7               .0200001
            14408
            ------
            15.1284
```

In division we locate the decimal point in the answer by moving the decimal in the divisor to the right as many places as necessary to make the divisor a whole number. Then move the decimal point in the dividend to the right the same number of places. The decimal point in the answer will be immediately above the new decimal location in the dividend.

Example 1. Divide 166.296 by 4.92.

```
Solution:  4.92 / 166.296
                        .
           492. / 16629.6
```

There are two decimal places in the divisor, so we move the decimal place two places to the right to make the divisor a whole number (492). Then we move the decimal place in the dividend an equal number of places to the right, making it 16629.6.

```
                      .
           492  / 16629.6
```

The decimal place in the answer will be immediately above this new decimal point in the dividend. Now we divide, being sure to place each number in the answer immediately above the *last* number of the part of the dividend we are using in that step. In this example, the first 3 in the answer is placed immediately above the 2 in the dividend, since the 2 is the last number in the part of the dividend we are using in this step (1662). The next 3 in the answer goes above the 9, and the 8 in the answer goes above the 6.

```
       33.8
492 /16629.6
     1476
     1869
     1476
      3936
      3936
         0
```

The answer is 33.8. To check, multiply the answer 33.8 by the *original* divisor 4.92.

Check:

```
   33.8
   4.92
    676
   3042
  1352
166.296
```

Since the answer to the check is the original dividend, the arithmetic is correct.

Example 2. Divide 32 by .016.

```
.016 /32
            .
016. /32000.
      2000.
016 /32000
     32
     000
```

The divisor decimal point is moved three places to the right. Three zeros are added to the dividend so that the decimal point can be moved three places to the right.

Check: 2000 x .016 = 32

Example 3. Divide 96.16 by .16.

Solution:

```
.16/96.16
          .
16. /9616.
      601.
16 /9616
    96
     016
      16
       0
```

Check:

```
 601
 .16
3606
 601
96.16
```

Example 4. Divide 2468.9 by 7.23.

Solution:

```
7.23/2468.9
             .
723. /246890.
         341.
723 /246890.
     2169
      2999
      2892
       1070
        723
        347
```

Notice that when we carried out the divisor the answer did not come out even, but that there is a remainder. In this case we may add zeros at the right of the decimal place in the dividend. We may continue this process as far as we wish.

```
          341.47
    723 /246890.00
         2169
          2999
          2892
           1070
            723
            3470
            2892
             5780
             5061
              719
```

For practice, solve the following problems:

1. 6.702 x 90.6031 =
2. 4321.001 x .008 =
3. 9.70101 x .000006 =
4. 15.1284 ÷ 2.1 =
5. 625 ÷ .125 =
6. 823.01 ÷ .0007 =

Changing Fractions to Decimals

In solving arithmetic problems in practical radio work, it will often be best to work out problems in fractions by means of decimals. It is an easy matter to convert any fraction to a decimal. It will be recalled that, near the first of this assignment, it was stated that a fraction was an indication of division. Thus 3/4 means, three divided by four. To convert this fraction into a decimal, all we have to do is to carry out this indicated division.

Example 1. Convert 3/4 to a decimal.

Solution:

```
     .75
  4 /3.00
     28
      20
      20
       0
```

$\frac{3}{4} = .75$

Example 2. Convert 1/8 to a decimal.

Solution:

```
     .125
  8 /1.000
      8
      20
      16
       40
       40
```

$\frac{1}{8} = .125$

Example 3. Convert 3/25 to a decimal.

Solution:

```
      .12
  25 /3.00
      2 5
       50
       50
        0
```

$\frac{3}{25} = .12$

Example 4. Convert 1/3 to a decimal.

Solution:

$$\begin{array}{r} .333+ \\ 3\overline{)1.000} \\ \underline{9} \\ 10 \\ \underline{9} \\ 10 \\ \underline{9} \\ 1 \end{array}$$

$\frac{1}{3} = .333 +$

The + indicates that this decimal did not come out even, but had a remainder. The number, .333, is accurate enough for all practical radio work.

Example 5. Add 7/8, 3/25, 2/5.

Solution:

$\frac{7}{8} = 7 \div 8 = .875$

$\frac{3}{25} = 3 \div 25 = .12$

$\frac{2}{5} = 2 \div 5 = .4$

Answer: 1.395

Example 6. Add 17 3/4, 22 3/16, 5 3/8.

Solution:

$\frac{3}{4} = 3 \div 4 = .75$

$\frac{3}{16} = 3 \div 16 = .1875$

$\frac{3}{8} = 3 \div 8 = .375$

$$\begin{array}{r} 17.75 \\ 22.1875 \\ \underline{5.375} \\ 45.3125 \end{array}$$

Answer: 45.3125

For practice solve the following problems using decimals:

1. Add 1/4, 1/5, 1/8.
2. Add 3/10, 5/8, 1/3.
3. From 3/4 subtract 1/3.

Percentage

Percentage is merely a useful way of comparing different quantities. The word percent (sometimes shown by the symbol%) means hundredth. Thus, 1 percent means 1/100 part.

Example 1. What is 1% of $500?

Solution: $1\% = \frac{1}{100}$

$\frac{1}{100} \times 500 = \$5$ (answer)

In this example, 1% is called the "rate", and 500 is called the "base".

Example 2. What is 2% of 1000 Volts?

Solution: $2\% = \frac{2}{100}$

$\frac{2}{100} \times 1000 = 20$ Volts

As we have learned previously, any fraction with 100 as a denominator may be written as a decimal. Therefore, since 1% = 1/100, it also equals .01. A simple way to solve percentage problems is to convert the percentage to a decimal and then multiply this decimal by the base. To solve Example 1 by this method, we follow the procedure below:

What is 1% of $500?

1% = .01

$$\begin{array}{r} 500 \\ \times\ .01 \\ \hline \$5.00 \end{array}$$

Answer: $5.00

Example 3. What is 5% of 75?

Solution: $5\% = \frac{5}{100} = .05$

$$\begin{array}{r} 75 \\ \times .05 \\ \hline 3.75 \end{array}$$

Answer: 3.75

Example 4. A certain voltmeter is guaranteed by the manufacturer to be accurate within plus or minus 2%. If the meter is indicating 8 Volts, how much error may there be?

Solution: 2% = .02

$$\begin{array}{r} .02 \\ \times\ \ 8 \\ \hline .16 \end{array}$$

Answer: .16 Volt error

Since the guarantee stated plus or minus 2% the actual voltage may be as high as 8 + .16 Volts, or 8.16 Volts; or it may be as low as 8 - .16 Volts, or 7.84 Volts.

Example 5. What is .5% of 50 Volts?

Solution: $.5\% = \frac{.5}{100} = \frac{5}{1000} = .005$

$$\begin{array}{r} 50 \\ .005 \\ \hline .250 \end{array}$$

Answer: .250 Volts

Example 6. A certain radio transmitter is 20% efficient. That is, its output is 20% of its input. If the input power of this transmitter is one kilowatt (1000 watts), what is the output power?

Solution: 20% = .20

$$\begin{array}{r} 1000 \\ \times\ .20 \\ \hline 200.0 \end{array}$$

Answer: 200.0 Watts

In radio work a different type of percent problem may be encountered.

Example 7. What percent of 8 is 7?

Solution: 7 is $\frac{7}{8}$ of 8, and $\frac{7}{8}$ = .875 = 87.5%

To solve this type of problem then, we divide the 7 by the 8 and then change this decimal to percentage. To change a decimal to percentage, move decimal point two places to right. Thus .875 = 87.5%.

Example 8. A certain radio transmitter has 600 watts output and 900 watts input. What percentage of the input is the output?

Solution: $\frac{\text{Output}}{\text{Input}} = \frac{600}{900} = \frac{2}{3} = .666 = 66.6\%$

For practice, solve the following problems:

1. 2% of 8 Volts =

2. .2% of 8 Volts =

3. 10.2% of 14 Volts =

4. 63% of 700 Watts =

5. What % of 700 is 400?

Significant Figures

In pure mathematics, a number is generally considered to be exact. For example, 110 would mean 110.000, etc., for as many zeros as we wish to add after the decimal point. In electronics work this is not always the case. For example, a certain switch board meter might read 110 volts, but a reading made with an expensive precision meter might indicate 110.2 volts. A series of precise readings might indicate the voltage to be 110.24 volts. Thus we can see that the 110 volt reading of the switch board meter was not an *exact* reading, but was an approximate reading. The 110 volts was approximately 110 volts, and not 110.000000 volts as in pure mathematics.

Any number representing a measurement, or the amount of some quantity, expresses the accuracy of the measurement. The figures required are known as the *significant figures*.

The significant figures of any number are the figures 1, 2, 3, 4, 5, 6, 7, 8 and 9, in addition to all zeros that occur between them.

Thus, .00368 volt has 3 significant figures.

.20007 amperes has 5 significant figures.

The zeros in .20007 fall in between the 2 and 7 and are significant figures.

73.25 has 4 significant figures.

47321.4 has 6 significant figures.

The number of significant figures in a meter reading, or in the answer to a problem, is a measure of the accuracy of the reading or answer.

Thus, one man worked out a simple electrical problem and calculated that 2.36 amperes flowed through a certain resistor and another man calculated 2.3623 amperes through the same resistor. The second man evidently worked the problem out more accurately.

In general, then, the greater the number of significant figures in an answer, the more accurate is the answer. A little common sense will go a long way in working with significant figures.

If you took a reading with a voltmeter and read 47.87 volts, you have four significant figures to work with. It might be better to call your reading 47.9 volts, or even 48 volts in many cases for the following three reasons:

A. Certainly, your eye isn't so good that you can read the average meter to four significant figures.

B. You might need only two significant figures, in which case the .87 volt is a needless display of accuracy.

C. The meter might only be accurate to within ± .5 volt in which case you have no assurance that the .87 volt has much significance.

Therefore the .07 volt could not be relied on.

In electronics and television work, an accuracy of three significant figures is sufficient.

Rounding Numbers

In "rounding off" the 47.87 volts to 3 significant figures (47.9 volts) and to 2 significant figures (48 volts), we follow a simple rule.

As you drop figures when rounding off numbers, try to make the remaining significant figures show values as close as possible to the original number.

Examples.

.00737373 to four significant figures = .007374. We increased the last 3 to a 4 since the next number was a 7 (larger than 5).

375.4381 to three significant figures = 375
49.371 to three significant figures = 49.4
80,750 to two significant figures = 81,000
.0303 to one significant figures = .03
3.3333 to four significant figures = 3.333
6.6666 to four significant figures = 6.667

If the number we drop is exactly 5 we can either increase or decrease the previous number.

37.5 to two significant figures = 37 or 38
.18250 to three significant figures = .182 or .183,

but .18253 to three significant figures equals only .183 since we know that the 5 is followed by a 3, and .53 is greater than one half.

For practice, round these numbers off to three significant figures:

1. 2,7382 =
2. .00047213 =
3. 9,777,700 =
4. 6.2914 =
5. .00300821 =

In this assignment we have covered the basic operations of arithmetic. These are: Addition, subtraction, multiplication and division. We have applied these operations to whole numbers, mixed numbers, fractions and decimals. We have also discussed percentage and rounding of numbers.

We suggest that you "work through" this assignment several times, concentrating particularly on any part of it that you find at all strange, or unfamiliar. As suggested at the first of the assignment *practice* on these parts until everything in the assignment is quite clear to you.

Test Questions

Be sure to number your Answer Sheet, Assignment 4.

Place your Name and Associate number on every Answer Sheet.

Send in your Answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

In answering these arithmetic problems, *show all of your work. Draw a circle around your answer.* Do your work neatly and legibly.

1. Multiply 378 x 226.

2. Add 21, 728, 64, 9643.

3. Divide 777 by 21.

4. Divide $\frac{5}{12}$ by $\frac{1}{3}$.

5. Multiply $\frac{294}{98} \times \frac{126}{56} \times \frac{112}{4}$.

6. Multiply 973.01 by .0063.

7. Divide 973.01 by .0063.

8. If a meter has an error of plus or minus 1%, how high and how low might the voltage actually be if the meter indicates 110 volts?

9. Multiply $7\frac{1}{7}$ by $4\frac{3}{4}$.

10. Convert these fractions to decimals, and add $\frac{7}{8}, \frac{9}{10}, \frac{3}{4}, \frac{1}{2}$.

Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

UEL

AN INTRODUCTION TO ELECTRICITY AND THE ELECTRON THEORY

ASSIGNMENT 5

ASSIGNMENT 5

AN INTRODUCTION TO ELECTRICITY AND THE ELECTRON THEORY

No one can learn a great deal about the theory and practice of electronics and television who does not also know a few of the fundamental facts about electricity and magnetism, for all electronics and television theory is built around these basic facts, and every circuit depends upon electricity for its operation.

A list of names of persons who have helped to develop the science of electricity would sound like a roll call in a league of nations. From Italy we have Luigi Galvani, and Alexandro Volta, the men who developed the voltaic cell. We honor Volta, when we use the term *volt* as the unit of electrical pressure. Everyone knows the name Gulielmo Marconi, who built up the transmission of radio signals and made it a commercial success.

Georg Simon Ohm was a German physicist who gave us one of the fundamental laws of electricity. In his honor we call the unit of electrical resistance the *ohm*. One of the later Germans, Heinrich Hertz, was the discoverer of Hertzian waves, or radio waves. His countryman, Wilhelm Conrad Roentgen, learned how to use electricity to produce X-rays.

From France we have Andre Ampere, for whom the unit of current strength is named; and also Charles de Coulomb, who made extensive researches in electricity and magnetism and took part in the development of the metric system. The unit of quantity of electricity, the *Coulomb*, is named in his honor.

Hans Christian Oersted, a Danish physicist, paved the way for the later researches of Michael Faraday; and his discoveries showed the close relationship between magnetism and electricity.

Crossing the English Channel to Scotland, we find such names as James Clerk Maxwell, the physicist, whose treatise on magnetism is still the foundation upon which our magnetic theory is built. England contributed J. J. Thompson, the man who proposed the electron theory, and Michael Faraday. Without Faraday's work we might still be depending upon voltaic cells for our commercial electricity.

In the United States, our own Benjamin Franklin proved that lightning was a form of electricity. Joseph Henry was a pioneer on self-induction, and was a leader in the practical development of the electromagnet. In his honor, the unit of inductance is called the *henry*.

We could go on and on mentioning the names of the men who have been instrumental in the development of electricity. In the practical field, we have Thomas A. Edison, inventor of the phonograph, the incandescent electric lamp and a storage battery. He was also a pioneer in the introduction of dynamo-electric machinery. Cyrus Field was an American who laid the first submarine Atlantic cable. In the field of communication, we find such names as Samuel Morse, Lee De Forest and Alexander Graham Bell. This list is by no means complete. It gives us only a glimpse of the many men who have helped to develop a field that can hardly be surpassed in interest or usefulness.

Electricity is certainly not a new discovery. As long ago as the year 600 B.C., the Greek philosopher Thales is said to have discovered that a piece of a substance called amber, which had been rubbed with flannel, would attract small pieces of paper. Nothing of value came from his discovery, however, and it seems to have been about 2200 years later that it was discovered that *many* subtances have this same property.

About 1600 A.D., William Gilbert made the discovery that different kinds of material can be excited by means of friction just as amber can. He gave the name electricity (from the Greek word for amber, "electron") to the phenomenon produced in this manner. He showed, too, that electricity and magnetism are not identical, although they have some properties in common.

In 1672, Otto Von Guericke constructed a crude electrical machine for producing static (or "at rest") electricity. This machine consisted of a ball of sulphur mounted on an axis. When the ball was turned, a hand held against its surface was electrified. An improved form of static electricity generator, as used in laboratories and for demonstration purposes, is shown in Figure 1.

In 1752, Benjamin Franklin performed his well-known experiment of flying a kite in a thunderstorm. He proved for us that lightning and electricity are identical, and that lightning is caused by atmospheric electricity. He also introduced the names of *positive* and *negative* for the two kinds of electricity.

(Incidentally, Franklin was a very lucky man in performing his experiments. Recent experiments, from the top of the Empire State Building, have shown that the current in a single bolt of lightning will range from one hundred thousand to two hundred thousand amperes.)

No doubt, you have noticed the crackling sound produced by rubbing a cat's back in dry, cold weather. In winter, a person sliding across a car seat can develop enough electricity by friction to get quite a shock when he touches the door handle. If your hair is dry, it flies out in all directions when you use a rubber comb, and the electrified comb will pick up bits of paper. All of these phenomena are due to "static electricity".

Some Experiments with Electricity

To detect the presence of a charge of electricity, we may use a pith-ball "electroscope". It consists of a ball of pith suspended from a support by means of a silk thread. If we electrify a glass rod by rubbing it with silk and hold this electrified rod near the pith-ball, we find that the pith-ball is first attracted to the rod and then repelled. This is illustrated in Figure 2. This same effect is produced if we rub a rod of hard rubber with flannel or cat fur and then hold it near the electroscope. It is interesting, too, to find that the silk, flannel, and cat fur also show signs of electrification when tested with the electroscope.

Let us charge a glass rod by rubbing it with silk and then suspend it by a silk thread, as shown in Figure 3. If we bring it near a second glass rod charged in the same manner, the rods repel each other. If we bring near the suspended glass rod a piece of hard rubber which has been electrified by rubbing it with cat fur, we find that the two rods are attracted to each other. By the same method, it can be shown that a charged rubber rod, suspended in the same manner, is repelled by a similarly charged rubber rod, but attracted by a glass rod electrified by rubbing it with silk. Thus, it seems obvious that there are two kinds of electricity.

An electric charge produced on a glass rod by rubbing the rod with silk is called a *positive charge*, and that kind of an electric charge produced on a hard rubber rod by rubbing it with a piece of cat fur is called a *negative charge*. Sometimes they are called *plus* and *minus charges*. These experiments have also demonstrated a basic law which can be stated as follows: *Like electrical charges repel; unlike electrical charges attract.*

We saw that when a charged rod is brought near a pith-ball electroscope, the pith-ball is first attracted to the rod, and then repelled. The charge from the rod spreads out over the pith ball until both are charged equally with electricity of the same sign. Then repulsion occurs. A more sensitive electroscope is shown in Figure 4. It consists of a brass rod terminating at one end in a brass ball or disc. The rod is thrust through a rubber stopper and suspended in a glass flask. To the lower end of the rod two strips of gold leaf, or aluminum foil, are attached. An electric charge applied to the ball, or disc, spreads down over the rod to the leaves, or foil, and since both leaves are thus charged with electricity of the same polarity, they repel each other. An efficient electroscope may be used to detect the presence of an electric charge, to determine its sign, or to measure its intensity.

It was pointed out in several of the examples, that the effect of the electric charge was felt before the charged object came in contact with the uncharged object. For example, if a charged rod is held near, but not touching, bits of paper, the bits of paper will be attracted and will jump to the charged rod. We see that the electric charge is exerting a force on these bits of paper, in spite of the fact that they are not touching. This force must be exerted through the air. The charged particle is said to be surrounded by a *field of force.*

This *field of force* is called an electric field of force, or more commonly an *electric field.* The term electric field merely means the region surrounding a charged body, wherein the charged body exerts force on other objects. If two bodies carrying the same charge are brought close together, their electric fields repel, and if two bodies with unlike charges are brought close together, their electric fields attract.

There are other fields of force besides the electric field. Gravity is an example of a field of force. When an object is dropped, it falls to the earth. This is because a field of gravitational force surrounds the earth. This field of gravitational force draws objects to the earth. Another field of force is the field of magnetic force that surrounds a magnet. This field will be studied in a later assignment.

Each of these *fields*, gravity, electric and magnetic, are different types of fields. *They are not the same things.* The only thing in common between them is the fact that they all exert force through the air. There is much that the scientists do not know about how these three fields are able to exert force through air.

Let us support the ball B, of Figure 5, by silk thread and then join the ball to the knob of an electroscope by means of a copper wire. If the ball B is then charged electrically, the charge is conducted or led along the copper wire to the electroscope, whose leaves diverge. If we were to repeat the experiment, but connect the ball to the knob of the electroscope by means of a silk thread, any change applied to the ball B does not travel to the electroscope, and there is no divergence of its leaves.

Materials which readily transmit an electric charge are called *conductors.*

Materials which do not readily conduct an electric charge are called *insulators.*

The Theory of Electricity

This force which we call electricity has caused many philosophers to wonder. We know electricity best by the effects which it can produce. It supplies us with light, it rings bells, it sweeps our rugs, it can be used for cooking and heating, and it even helps us to keep time. We shall learn in this course that radio waves are merely a form of electricity.

In his theory of electricity, Benjamin Franklin assumed that electricity is a *fluid*. He assumed that any object which is positively charged has an excess of this electrical fluid; if an object has less electrical fluid than normal, he considered it as negatively charged. Just as heat is believed to flow from objects of high temperature to those of a lower temperature, so Franklin assumed that electricity flows from positive (plus) to negative (minus). Although Franklin's theory is out-of-date and certainly incorrect, yet it was used so long that a large number of books and texts still use diagrams that represent electric current as flowing from the positive to the negative terminal. We know now that the electric current consists of a stream of electrons, instead of a fluid as Franklin supposed, and that it flows from the negative terminal to the positive.

The electron theory has superseded Franklin's theory and has come to be considered as the correct theory. To understand the electron theory, we must know something of the nature of matter.

Suppose that a piece of some solid object - a piece of copper wire, for instance - is examined beneath a very powerful microscope. It will be seen that the copper appears to be composed of small particles or grains held together in some mysterious manner. These grains are called "crystals" of copper, and through the use of an electrically controlled instrument, the Electron microscope, a single crystal can be made to appear quite large.

It is well known that ordinary light will not pass through a metal, but a beam of X-rays will penetrate thin sheets of metal very easily. X-rays are fundamentally of the same nature as visible light, but their frequency is much higher and they contain much more energy. If a beam of X-rays were directed on one of these single crystals of a metal, the X-rays will pass through it, coming out on the other side. By photographically studying the directions from which these rays emerge, it can be determined that the crystal of the metal is composed of rows upon rows of small particles arranged in the form of a lattice structure. An example of this is shown in Figure 6. Each of these little submicroscopic particles is thought to be an *atom* of the metal.

In the crystals of the copper, the atoms are considered to be held in fixed positions within the crystal. However, in a gas, the atoms are not fixed in position, but move about freely within the container holding the gas. But whether in a solid or a gas, the individual atoms themselves are made up in a very definite way.

Until the intensive research on the construction of the atom which took place during the war, it was believed that there were 92 separate and distinct types of atoms. The atomic research of the war revealed at least three more types of atoms. Each type of atom accounts for a different *element*. An element is defined as a substance which cannot be separated into substances different than itself by ordinary chemical means. Examples of elements are: Oxygen, tin, gold, copper, etc.

An atom is considered to be made up of three kinds of particles. These three particles or "atomic building blocks" are:

1. The *electron* which has a *negative* charge.

2. The *proton* which has a *positive* charge. Its charge is just equal in magnitude to the charge of the electron, but of course, opposite in polarity.

3. The *neutron* which has mass, or weight, but no charge.

The proton and neutron are equal in weight, being 1849 times as heavy as an electron.

All atoms are composed of these three "building blocks". The thing that determines the characteristics of the different elements, iron and oxygen for example, is the number of each of these "atomic building blocks" in each atom and the arrangement of these particles. For example, an atom of hydrogen contains only one proton, one electron and no neutrons. This atom is the lightest in weight of all atoms. An atom of helium contains two protons, two electrons, and two neutrons. An atom of helium is shown in Figure 7.

All electrons are identical regardless of what element they are in. For example, the electrons in an atom of tin are the same as the electrons in an atom of helium. Also, all protons are identical regardless of the element, in which they are located. This is also true of the neutrons.

All atoms, in their normal state, are neutral. That is, they have no charge. This is because they contain an equal number of electrons and protons.

The electrons, protons and neutrons are not uniformly distributed throughout the space occupied by an atom. The protons and neutrons are grouped together in the center of the atom, as shown in Figure 7. This center portion, consisting of the protons and the neutrons, is called the nucleus. Since all of the protons, or positive charges, are contained in the nucleus, the net charge of the nucleus is positive. Circulating around the nucleus in orbits are the negatively charged electrons. This rotation of the electrons around the nucleus is very similar to the rotation of the planets about the sun in the solar system. The negatively charged electrons are attracted to the nucleus due to the fact that unlike charges attract. Why these electrons do not go directly into the nucleus is as difficult to explain as why the earth doesn't go directly to the sun.

This theory of the construction of matter is called the electron theory, and was proposed by the English scientist, J. J. Thomson.

While the neutrons are fundamental "atomic building blocks", they contain no electrical charge; so we can neglect them in our discussion of the action of an atom as far as the electrical charges are concerned.

Applying this electron theory to the glass rod of our earlier experiments, we see that the glass rod would be made up entirely of electrons, protons and neutrons. The protons are believed to be fixed in the atoms, but the electrons are loosely held and are transferable. When the number of protons and electrons are equal, the rod has no electrical charge. But when we rubbed the glass rod with a piece of silk, some of the electrons were brushed off the glass and became a part of the silk. This caused the glass to have a *deficiency* of electrons, or to put it another way, an *excess* of protons, giving it a resultant net charge which was positive. This was shown by the electroscope. The silk had an excess of electrons, giving it a *negative* charge, and this could also be shown on the electroscope. Therefore we can conclude, that to have electrification, there must be either an *excess of electrons* or a *deficiency of electrons*. An *excess of electrons* produces a negative charge, and a *deficiency of electrons* produces a positive charge.

The Electric Current

In many ways, the action of electricity can be compared to water. Water at rest is not doing any work. Similarly, electricity at rest (static electricity) does no work. When water flows from one point to another, it can be used to do work--turn dynamos, mill wheels, etc. When an electrical charge moves from one point to another, it, too, can do work--turn a motor, heat a toaster, etc. The movement of an electric charge along a conductor is called an electric current.

Thus, static electricity is produced by electrons at rest, and current electricity is electrons in motion. Electrons streaming along a conductor form an electric current, but we cannot have an electric current unless we *build up a difference in potential between two points on a conductor, or in a circuit.* Then we shall have an excess of electrons in one part of the circuit and a deficiency in another part. If the difference of potential is maintained, a *continuous current will flow through the circuit.*

To compare these statements to an easily understood example let us assume that we have two vertical cylinders connected near the bottom with a pipe in which there is a stopcock. Such an arrangement is illustrated in Figure 8. Cylinder A is filled with water to the line C, and cylinder B is filled to the line D. If we open the stopcock, water will flow from A to B, but the flow will stop as soon as the water level is the same in both cylinders. The current stops flowing when there is no longer a difference of pressure. It is possible to put a pump into the circuit and keep pumping water from B into A, just fast enough to maintain the same difference of pressure as we had in the beginning. As long as a constant difference in pressure is maintained by the pump, a constant amount of current will flow from cylinder A to cylinder B.

Suppose that we have two bodies connected by a copper wire such as shown in Figure 9. One of these bodies is positively charged (that is, has too few electrons), the other is negatively charged (an excess of electrons), and the two are connected by a copper wire which has a free interchange of electrons.

At the instant the two bodies are connected, the positive body will attract electrons associated with the atoms at the end of the copper wire, and will pull some of them out. This will provide the positive body with the electrons it needs, and this body will become neutral, or have an equal number of positive and negative charges. Pulling electrons from the end of the copper wire will however tend to leave this section of the wire positive and it will attract electrons from the next section of the wire. This portion of the copper wire will, therefore, pull electrons from the next section, and so on until the distant end is reached. Here this last portion of the wire can take electrons from the negative body since the negative body has an excess of them. Through this action, which occurs very rapidly, the two charged bodies become neutral; that is they each now contain equal numbers of positive and negative charges.

A review of this action shows this: At the instant the copper wire was attached between the two unequally charged bodies (and probably for a brief instant afterwards) *electrons moved within the copper wire.* The direction of their motion was from the negative body to the positive body. Also, it was seen that the motion of electrons soon ceased, because when the charges on the bodies became equalized, there was no attracting force left to cause the electrons to flow. This flow of electrons is considered *an electric current.* Thus, *an electric current may be defined as a progressive flow of electrons.*

In an ordinary piece of copper wire the electrons are moving about in a haphazard fashion at the rate of about 35 miles per second. If there is a difference of electrical potential between the two ends of the wire, or in other words, if the ends of the wire are connected to a battery, in addition to this to and fro motion, there is a comparatively slow drift of electrons from one end of the wire to the other. It is this slow drift of electrons in a given direction that we ordinarily call the electric current. Because each electron can carry an extremely small quantity of electricity, it is only movements of large numbers of them in which we are interested. It has been estimated that it would take all the inhabitants of the earth, counting night and day at the highest rate of speed possible, two years to count the number of electrons which pass through an ordinary 40 watt electric lamp bulb in a second. This is about the same number of electrons necessary to operate a modern ac-dc table model radio.

At this point it will be well to clear up one misunderstanding which has existed for some time. This is the matter of the direction of current flow. It was pointed out in the explanation of the electron theory, that the current flows from the negatively charged body to the positively charged body. This has been definitely proved to be true. Prior to the electron theory, Benjamin Franklin's "fluid" theory was used and current was assumed to flow from positive to negative. A great number of books have been written employing this incorrect idea. These books are still in existence. Also some modern texts are still being written using this idea of current flow. This is particularly true of books for "power men" rather than electronics men. For this reason you may find other texts which will state that current flows from positive to negative, but do not let this confuse you. *Current*, which is a slow drift of electrons, *flows from negative to positive.* In this training program the flow of current will always be assumed to flow from the negatively charged body to the positively charged body.

The unit which is used to measure the amount of electricity flowing in a circuit, is the "ampere". When 6,280,000,000,000,000,000 electrons are flowing past a point in one second, one ampere of current is flowing. This term ampere, and fractions of it, will be encountered very often in electronics, so remember, *it is a measure of the current flowing in a circuit.* The abbreviation used to represent ampere is (a or A). Thus, 3a means 3 amperes, and 10A means 10 amperes.

Of course, we can't count the electrons flowing in a circuit, to find out how much current is flowing. Instead, the amount of current flowing in a circuit is measured with a meter called an *ammeter.*

Insulators and Conductors

It is common knowledge that current does not flow through the non-metallic parts of a radio set and that it does flow through the metallic parts (wires etc.). We see the wires on the power line poles supported by insulators. We may wonder why some materials will carry an electric current and others will not. The answer to this is found in the electron theory of matter.

In the materials which are good conductors, some of the electrons are not held tightly in their orbits. When these atoms are subjected to a difference in potential, these loosely-held electrons are free to move from one atom to another. These electrons, which are free to move from one atom to another, are called "free electrons". This movement of free electrons is the flow of current which we have been discussing. In the materials which are called insulators, all of the electrons are held tightly in their orbits. When these atoms are subjected to a difference in potential, very few free electrons are present, so only a *very, very small* current flows. Some good insulators are glass, rubber porcelain, quartz, silk and dry air. The best electrical conductor is silver. It is seldom used due to its expense. Copper is the next best conductor and is widely used. Aluminum is the next best commonly used conductor. There is no such thing as a perfect insulator or a perfect conductor. The best insulators will have a *few* free electrons and will allow a small electric current to flow if subjected to a difference in potential. Also, even the best conductor, silver, offers some opposition to the flow of an electric current.

Between these two extremes (insulators and conductors) will be found a large number of materials which are neither good insulators nor good conductors. These materials are sometimes called semi-conductors, but are more often called resistors. A resistor, then, is a material which opposes the flow of an electric current. The unit of electrical resistance is the "ohm". Some commonly used resistance materials are carbon and iron.

The unit of resistance, the "ohm", was named in honor of George Simon Ohm. It is arbitrarily defined by international agreement, as the resistance of a column of mercury weighing 14.4521 grams, having a uniform cross section, and a height of 106.3 centimeters at 0^{o} centigrade. The "ohm" will become a more practical term when you consider the fact that a 9.35 foot length of number 30 copper wire will have one ohm resistance. There is approximately one ohm of resistance in 1000 feet of number 10 copper wire. In electronics circuits, resistors will be found in the range from a few ohms to about 10 million ohms. The Greek symbol omega (Ω) is often used to indicate ohms.

The property of a resistor, that of *opposing* the flow of an electric current, is called resistance. This property is just the opposite of the property of a conductor. The property of a conductor is to *allow* the flow of an electric current. This property is called conductance. The unit of conductance is just the opposite of the unit of resistance, that is, it is the same word spelled backwards. The unit of conductance is the "mho".

Potential Difference

We have seen that an instantaneous electric current composed of electrons flows from one electrically charged body to another if their electric charges were different. Now, instead of always speaking of differences in electric charges, we commonly call it a *difference of potential*. The word "potential" has several meanings, but the best one to use here is "inherent ability". Thus, when two bodies have unequal charges--as we have been considering--they have a difference of potential; that is, they have the *inherent electrical ability* to cause a current to flow through the copper wire. In other words, *a potential* *difference may be defined as the electrical condition, or force, that causes or tends to cause an electric current to flow.*

In measuring altitudes, sea level is usually used as a reference, and certain localities are referred to as being above or below sea level. Similarly, in electrical and electronic work, a body (such as the earth or the metal chassis) may be taken as a reference and electrically charged bodies may be specified as being so many volts above or below this zero potential.

Electromotive Force

We have seen that an electric current would flow through a conductor such as a copper wire if the two ends of the wire were at a difference of potential. In the circuit of Figure 9, the potential difference was provided by two unequally charged bodies, and as soon as the unequal charges were neutralized, the current ceased to flow. Of course, this was because after neutralization no difference of potential was present to force the electrons along the wire.

Let us add a third element to Figure 9, making it appear as Figure 10. This new element has been connected to the positive and negative bodies, and since this new element has the property of maintaining these bodies positive and negative, a *constant* difference of potential will exist and a continuous current will flow.

When a device such as shown in Figure 10 maintains one body positive and another negative, it is the common practice to say that the two bodies are maintained at a difference of potential because of the "electromotive force" that the device generates. In electronics, we often abbreviate the words "electromotive force" as "emf". *An electromotive force may be defined as the electric force generated by a device (such as a battery or generator) that causes a difference of potential to exist between the terminals of the device.* Thus, the emf that is produced by batteries and electric generators is the force that pushes or forces an electric current through the external circuit connected to the battery or generator, and it does this by establishing a difference of potential between its terminals.

The emf is measured in Volts. Thus, if we have a 45 volt battery, this means that the battery will maintain a difference of potential of 45 volts between its terminals. You will find the terms voltage, difference in potential, potential difference, and emf all used interchangeably. The abbreviation used to represent voltage is V. Thus, 45 V means 45 Volts. Voltage is measured by a meter called a Voltmeter.

Types of Current

The type of current which flows in a circuit when a constant difference in potential, such as that produced by a battery, is maintained is called a direct current. This current is always flowing in the same direction through the conductor and is substantially constant in magnitude. Thus, if there is one ampere of current flowing at one instant, there will still be one ampere of current flowing at some later instant.

Later in the training we shall encounter other types of current. One of these types is called pulsating direct current. This is a current which is always flowing in one direction, but varies in magnitude. Thus, if there is one ampere at one instant, at some later instant there may be 5 amperes or 1/10 amperes of current flowing in the circuit.

Still another type of current is the alternating current. This type of current is periodically changing in direction, and always changing in magnitude. This is the type of current supplied to the house lighting circuits of most communities. We will study this type of current in great detail in future assignments.

Units of Current, Voltage and Resistance

The fundamental units used to measure current, voltage and resistance are sometimes rather unwieldy to use when discussing electronics circuits. For example, it is very common to find currents in the neighborhood of one one-thousandth of an ampere flowing in a radio circuit. We will also encounter resistances of several million ohms. To eliminate the use of these large numbers and fractions, a number of sub-units or multiple units are used. The table of these units is given below. The last column gives the abbreviation used for these units.

Unit	Stands For		Abbreviation
	Fraction	Decimal	
Milli	$\frac{1}{1000}$	.001	m
Micro	$\frac{1}{1,000,000}$	.000001	μ (Greek letter mu)
Micro-Micro	$\frac{1}{1,000,000,000,000}$	.000,000,000,001	$\mu\mu$
Kilo	1,000		K (sometimes large M)
Meg	1,000,000		Meg

Let us see how we would use these units to represent the one-one thousandth of an ampere mentioned previously. Looking at the table we find that milli stands for one-one thousandth, so this value of current is commonly called one milliampere, and is abbreviated 1 ma. To represent a value of 10 million ohms we would use 10 megohms. To represent one millionth part of a unit we would use the term micro. For example, the current flowing in the "picture tube" in a television receiver might be 1 microampere. This would be written, 1 μa. Some television receivers use voltages of 15 thousand volts. This would be indicated by 15 KV.

Let us re-emphasize these facts. Current is the *flow of electrons* in a conducting medium. Voltage is a measure of the *force* that causes the current to flow. Resistance is the *opposition* offered to the flow of an electric current.

A summary of the material covered in this assignment follows:

Atoms are composed of electrons, protons and neutrons.

Electrons have a negative charge.

Protons have a positive charge.

Neutrons have no charge.

Protons and neutrons form the nucleus of the atom.

Electrons revolve around the nucleus in fixed orbits.

The normal atom is "balanced" electrically; that is, it has an equal number of electrons and protons.

Some materials, called conductors, have "free electrons"; that is, electrons which are not tightly held in their orbits.

Insulators have all of their electrons tightly held in their orbits.

An electric current is the flow of free electrons along a conductor. An electric current will flow through a conductor if a difference in potential exists across that conductor.

An electric current is measured in amperes. (Abbreviated A)

Difference in potential is measured in volts. (Abbreviated V)

Resistance is the opposition offered to the flow of electric current. It is measured in ohms.

Current flows from the negative terminal of a battery, through the circuit to the positive terminal.

We saw earlier how the electrons making up the current are driven through the wires and other elements making up a circuit by a force which is known as an electromotive force. The unit of this force is known as the "volt". A volt is the electrical force that will cause 1 ampere of current to flow through a wire which has 1 ohm of resistance.

Thus, it is possible to know three things about every circuit carrying a current. These are: (1) the strength of the current, (2) the voltage in or across the circuit and, (3) the resistance in the circuit. In a future assignment we will learn how to find the third of these when any two of the three are known.

From this assignment the trainee should attempt to get a clear picture in his mind of what the construction of an atom is like. Then remember these facts:

(1) The positively charged protons *do not move* from atom to atom.
(2) Some atoms do not hold their negatively charged electrons very tightly. These loosely held, or free electrons, may move from one atom to another. The movement of these free electrons in some definite direction constitutes the flow of an *electric current.* Electric current is measured in amperes.
(3) If any body has more than its normal amount of electrons, that body will have a *negative charge.*
(4) If a body has fewer electrons than normal, that body will have a *positive charge.*
(5) The difference in electrical charge of bodies is called the difference in potential.
(6) Difference in potential is measured in volts.

These statements have been repeated for but one purpose. That is, to enable the trainee to understand the difference between voltage and current. Remember, voltage is the electrical pressure, and current is the movement of electrons which result when electrical pressure is applied.

Test Questions

Be sure to number your Answer Sheet Assignment 5.
Place your Name and Associate Number on *every* Answer Sheet.
Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. State the basic law for electrical charges.

2. What is the essential difference between a conductor and an insulator?

3. In the electron theory, does an electric current flow from *positive to negative* or from *negative to positive?*

4. What is an electron?

5. What is an electric current?

6. (a) How many ohms are there in a megohm?

   (b) How many milliamperes are there in an ampere?

7. What is the unit of resistance?

8. (a) List three good conductors.

   (b) List three good insulators.

9. What is the name of the force which causes electrons to move in a circuit?

10. Is current measured with an *ammeter* or a *voltmeter?*

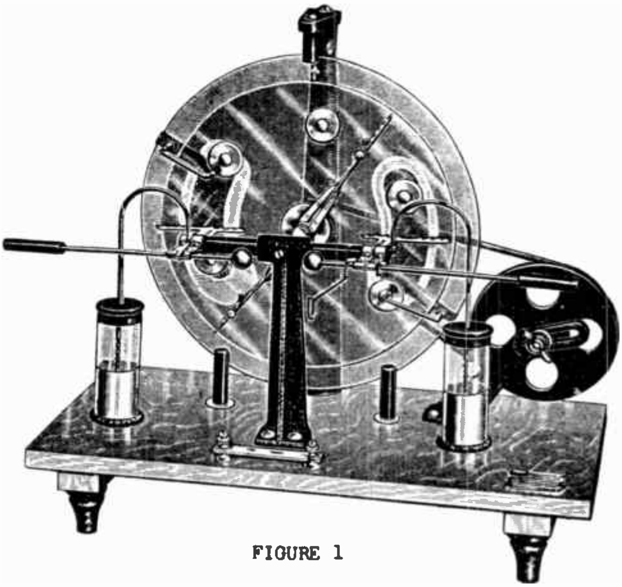


FIGURE 1

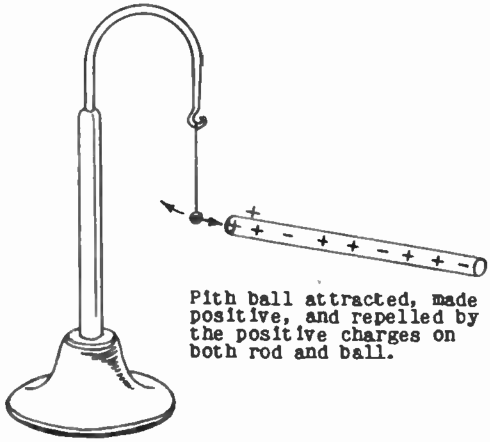


FIGURE 2

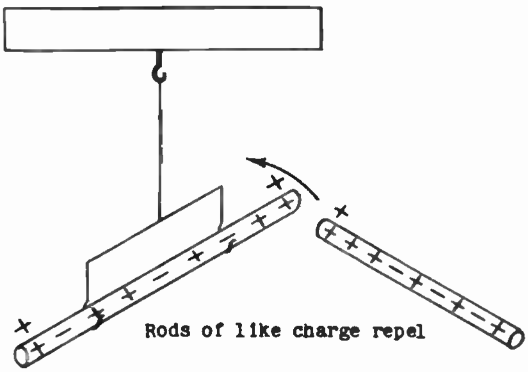


FIGURE 3

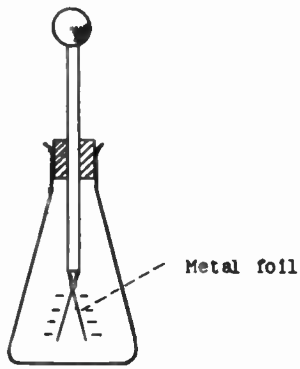


FIGURE 4

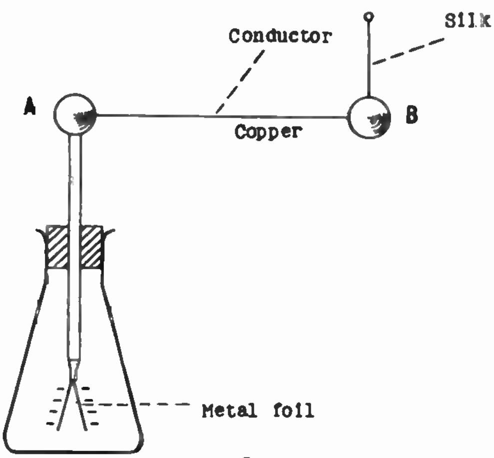


FIGURE 5

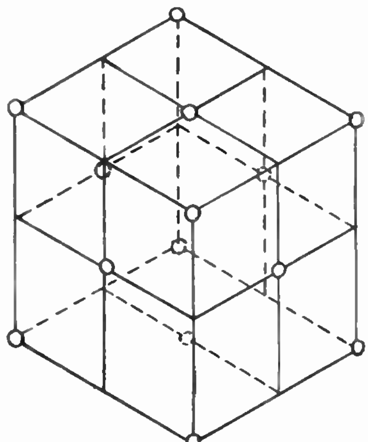


FIGURE 6

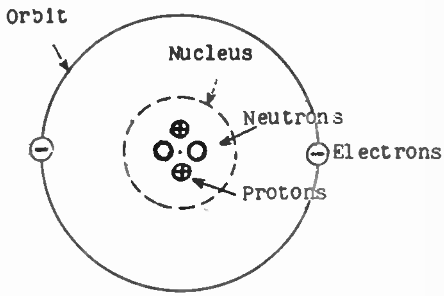


FIGURE 7

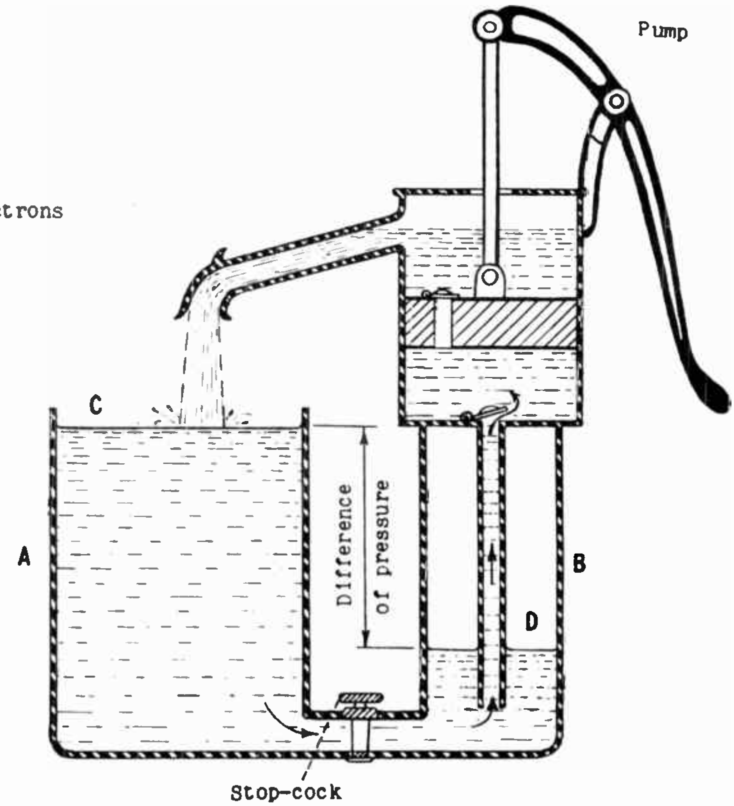


FIGURE 8

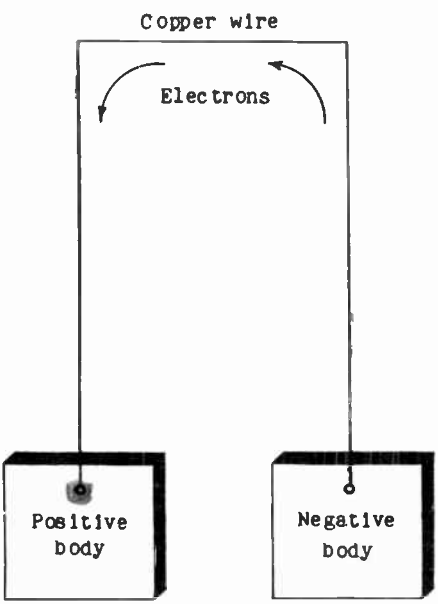


FIGURE 9

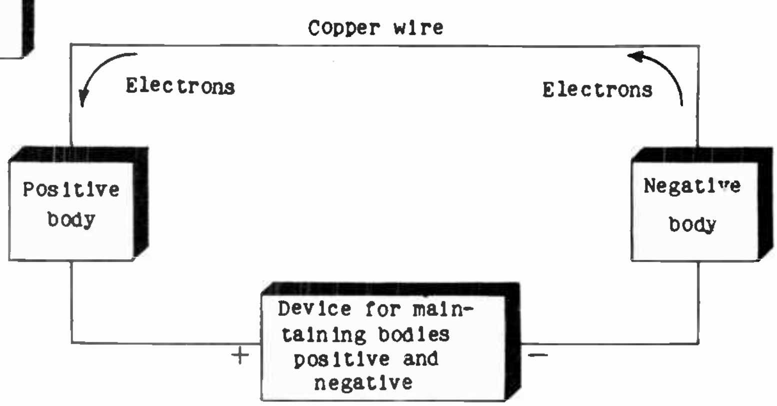


FIGURE 10

Electronics

Radio

Television

Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

DIRECT-CURRENT CIRCUITS---OHM'S LAW

ASSIGNMENT 6

ASSIGNMENT 6

DIRECT-CURRENT CIRCUITS---OHM'S LAW

In the preceding assignment which dealt with the fundamentals of electricity it was pointed out that there are three basic factors which are present in d-c circuits. These three factors are; (1) Voltage, (2) Current, and (3) Resistance. To have a thorough understanding of the operation of the circuits in electronic and television equipment the Associate will have to understand just what voltage, current, and resistance are and will have to understand the relationship which exists between these three factors. The relationship between voltage, current and resistance is commonly called Ohm's Law and will be considered in greater detail later in this assignment. Before proceeding with Ohm's Law, however, it will be well to further illustrate the basic factors of voltage, current and resistance so that the Associate will have a clear understanding of what each of these factors actually means in a circuit, the units in which these factors are measured, the range of values of these units which will normally be encountered in electronics and television equipment, and the abbreviations and symbols used to represent these factors. These points were considered in the preceding assignment but will be taken up again at this time to provide greater clarity for the Associate.

Voltage

Voltage is the term used to indicate the amount of electromotive force present. Let us consider this term, electromotive force, in more detail before proceeding. The electro- portion of this term means; having to do with electricity. The -motive force portion of this term means; a force capable of producing motion. Thus the entire term means the force capable of producing a motion of the electricity in a circuit, or in other words, the force capable of causing the electrons to move within an electrical circuit. The electromotive force (abbreviated emf) is, therefore, the amount of electrical pressure in a circuit. In a water system, the pressure is measured in pounds per square inch; in an electrical system the pressure (emf) is measured in volts, and the electrical pressure is generally referred to as the voltage in the circuit. There are three types of voltage; d-c voltage, pulsating d-c voltage and a-c voltage. In this assignment we will devote our attention to circuits employing d-c voltages. A d-c voltage is one which remains constant.

D-C voltages may be generated, or produced, in a number of different ways. Figures 1 and 2 illustrate a number of common voltage sources. Figure 1 illustrates several types of cells and batteries. (The term battery actually means a battery of cells, or in other words a group of cells.) Figure 1(A) shows a penlight cell, Figure 1(B) shows a flashlight cell and Figure 1(C) shows a size No. 6 dry cell. Each of these cells produces an emf of approximately 1.5 volts. In other words, the voltage of each of these cells is approximately 1.5 volts. Everyone is familiar with the use of the penlight cell and the flashlight cell. Size No. 6

dry cells are used in some doorbell circuits, in rural telephone circuits and in the old style battery operated radios.

The battery illustrated in Figure 1(D) is commonly referred to as a "B" battery. This battery produces an emf of approximately 45 volts. This type of battery was used very widely in the older types of battery radio receivers and smaller versions of this battery are used in the modern portable battery type radio receivers. The storage battery illustrated in Figure 1(E) produces an emf of approximately 6.3 volts. This type of battery, of course has been used very widely in automobiles.

Figure 2 illustrates two other sources of d-c voltage. These are the d-c generator shown in Figure 2(A) and the power supply shown in Figure 2(B). D-C generators may be constructed to produce output voltages ranging from a few volts to 1000 or more volts depending upon the application for which the generator is intended. A power supply arrangement somewhat as illustrated in Figure 2(B) is the most common d-c voltage source which will be encountered in electronic and television equipment. In practically all localities the voltage delivered by the power companies to the homes for lighting, heating, etc., is a-c voltage. However, the correct operation of the major portion of the circuits in electronic and television equipment requires d-c voltages. A power supply circuit is able to convert the a-c voltage into a d-c voltage for use in this equipment. In industrial electronic equipment, the power supply is often built on a separate chassis in an arrangement similar to that of Figure 2(B). However, it is much more common in radio and television equipment to find the power supply built on the same chassis as the remaining portion of the equipment. The power supply shown in Figure 2(B) is one which you will construct in Home Laboratory Experiment No. 3.

The amount of voltage produced by the power supplies in electronic and television equipment is dependent largely upon the design of the unit. For example, the power supply in a small a-c, d-c portable radio receiver usually delivers an emf of approximately 90 volts. In the larger types of radio receivers the power supplies normally produce voltages ranging between 250 volts and 300 volts. Television receivers normally employ at least two power supplies, one of which produces a voltage of approximately 300 volts while the other power supply delivers a very high d-c voltage ranging from 9,000 volts in black-and-white receivers to 27,000 volts in color TV receivers.

As mentioned, the cells and batteries illustrated in Figure 1 deliver voltages of 1.5 volts, 6.3 volts and 45 volts. However, it is sometimes inconvenient to spell out the entire word volts and the abbreviation V is often used to indicate the word volts. For example, a battery symbol is a schematic diagram may appear as shown in Figure 3. The 6.3 V alongside this battery symbol indicates that it produces an emf of 6.3 volts.

In addition to the battery voltages and power supply voltages in electronic and television receivers other voltages are present. These voltages range from a value of several millionths of a volt to several volts. Thus it can be seen that a very wide range of voltages may be encountered in electronic and television equipment when it is considered that the high-voltage power supply in a television receiver delivers many thousands of volts. While the various voltage values encountered could be expressed as so many thousandths of a volt or so many millionths of a volt or so many thousands of volts it is more convenient to use prefixes with the term volt to indicate the size. The prefix used to indicate one thousandth of a volt is the prefix milli, the prefix used to indicate one millionth of a volt is micro, and the prefix used to indicate thousands of volts is kilo.

Thus: 32 thousandths of a volt, or .032 volt, is normally expressed as 32 millivolts.

14/1,000,000 volt, or .000014 volt, is expressed as 14 microvolts.

8,000 volts is expressed as 8 kilovolts.

As pointed out the abbreviation V is often used to indicate the term volts. Likewise abbreviations are used for the prefixes milli, micro, and kilo, These are:

milli	m
micro	μ
kilo	k

Thus the figures stated above might be abbreviated as follows:

32 millivolts	abbreviated 32 mv
14 microvolts	abbreviated 14 μv
8 kilovolts	abbreviated 8 kv

Two other terms which are often used to indicate that an electromotive force is present in a circuit are: (1) difference in potential and (2) potential difference. Remember, however, that each of these terms is merely another way of saying electromotive force, and each is measured in volts. Thus, an emf of 18 volts, a voltage of 18 volts, a difference in potential of 18 volts, or a potential difference of 18 volts all mean the same thing.

Since the abbreviation V may be used in place of the longer term volts it would seem logical that in an electronic formula dealing with voltage, V would be employed. Unfortunately however, this practice is not followed. Instead, the symbol E is used to represent voltage in radio formulas. In this case, the E is an abbreviation of the term electromotive force. To illustrate this fact, let us suppose that you saw the electronics formula E = I x R. In this case, the E stands for the electromotive force in volts.

Since the unit of electromotive force is the volt, the amount of electromotive force is measured with a voltmeter. The arrangement employed is illustrated in Figure 4. Figure 4(A) shows a pictorial diagram in which a voltmeter is connected to the dry cell to measure the amount of voltage produced. Figure 4(B) shows a schematic diagram of this same circuit. Notice that there are two leads on a voltmeter and to use a voltmeter to measure the voltage output of a dry cell, one of these leads is connected to the positive terminal of the cell and the other lead is connected to the negative terminal of the cell. Voltmeters are manufactured in a wide variety of ranges so that a suitable meter can be used for measuring most any voltage value. For example, in measuring a cell as in Figure 4 which delivers approximately 1.5 volts a voltmeter having a full scale reading in excess of 1.5 volts would be employed. For example, a meter with a full scale reading of 2 1/2 volts, 3 volts, 5 volts or possibly 10 volts would be employed. If a voltmeter is to be used to measure the output of the power supply which is illustrated in Figure 2(B) the full scale reading must be equal to or in excess of the voltage output of the supply. In this case a voltmeter with a full scale reading of 300, 400 or perhaps 500 volts would normally be employed. Voltmeters are also available for use in measuring values of voltage in the thousands of volts. These meters are commonly called kilovoltmeters. Voltmeters may also be obtained for measuring very small values of voltage. For example, a millivoltmeter would be employed if it were desired to measure voltages in the range of a few thousandths of a volt. Some typical voltmeters are shown in Figure 4(C).

To summarize this discussion on voltage it can be stated that the electromotive force in a circuit is measured in volts. It is this electromotive force or voltage which is the force in an electric circuit which can cause the various actions of the circuit to take place. It is the voltage which causes the current to flow in an electric circuit. Notice, however, that voltage and current are two entirely different things. The voltage is the force which causes current to flow in a circuit.

Current

When an emf is applied to a complete electrical circuit there is a motion of the electrical energy through the circuit. As explained in the previous assignment the condition which actually occurs is that the free electrons move through the circuit from the negative terminal of the voltage source toward the positive terminal. In other words, the electrons flow through the circuit. This motion of free electrons in an electrical circuit is called the current. The motion of the electrons in the circuit, or in other words, the current flowing through the circuit, cannot be seen. However, the effects of this current can be noted. It is the current flowing through the circuit which enables an electric motor to operate, which causes an electric stove to heat, which enables a loudspeaker to produce sound waves when it is connected to a radio receiver and which makes it possible for a television receiver to produce a picture of a scene taking place many miles away.

In a water system the flow of water, or in other words the current of water, is measured in gallons per minute. In an electrical circuit, current is measured in amperes.

The ampere is a rather large unit of current. To illustrate, when an electric iron is connected to an ordinary house wiring circuit only 6 to 10 amperes of current will flow through the iron, approximately one ampere of current will flow through a 100 watt light bulb when connected to the normal lighting circuit, and approximately 2/10 ampere flows through the bulb in a normal two-cell flashlight when the flashlight is turned on. The current which flows from the power supply to the various circuits in a normal radio receiver will range between .015 of an ampere and .075 of an ampere, and the current supplied by the power supply in a television receiver will range from approximately .075 of an ampere to .300 of an ampere. From this it can be seen that current in the order of amperes will seldom be encountered in radio and television circuits. For this reason the prefixes milli and micro are used in conjunction with the term ampere quite often. As mentioned previously the prefix milli means "one thousandth part of," and micro means "one millionth part of." To illustrate the use of these terms let us suppose that one thousandth of an ampere (.001 ampere) of current flows from the power supply in a radio receiver through a particular vacuum tube circuit. In this case a technician would normally state that 1 milliampere of current is flowing in the circuit. Similarly if 15/1000 of an ampere of current flows through the circuit connected to an industrial electronic power supply a technician would normally state that 15 milliamperes of current flows in the circuit. Similarly, if 10/1,000,000 of an ampere of current flows through the circuit connected to the high-voltage power supply in a television receiver a technician would state that 10 microamperes of current flows in the circuit.

Thus 5/1000 ampere or .005 ampere = 5 milliamperes (5 ma).
30/1000 ampere or .03 ampere = 30 milliamperes (30 ma).
20/1,000,000 ampere or .000020 ampere = 20 microamperes (20 μa).

It will be noted in the above, that to eliminate the necessity of writing out the word ampere in full, the abbreviation a is commonly used for the longer term ampere.

When current is to be used in an electronic formula the letter I is used to indicate it. Thus, in the formula E = I x R, the I stands for current in amperes. The letter I is used for current since current is a measure of the intensity of the electron flow in a circuit.

The current which flows in a circuit can be measured by means of an ammeter or milliammeter. Figure 5 shows the manner in which this could be done. Notice that it is desired to determine how much current is flowing in the circuit. Thus the ammeter or milliammeter must be connected so that the current from the battery flows through the meter at the same time it is flowing through the remaining portion of the circuit. Notice in the circuit of Figure 5 that the current would flow from the negative terminal of the dry cell, through the resistor, through the meter and return to the positive terminal of the dry cell. Thus, the current which flows through the resistor will also flow through the meter, and the meter will indicate the amount of current flowing in the circuit.

Current measuring meters are manufactured in a wide variety of ranges so that a suitable meter can be used with most any circuit. For example, if it is desired to measure the exact amount of the current flowing in a circuit in which the current is in the order of several amperes, an ammeter which has a higher full scale reading than that which is flowing in the circuit would be employed. If, however, the circuit consists of a radio or television circuit in which a few milliamperes of current are flowing the current indicating meter employed will normally be a milliammeter. To illustrate; if approximately 3 milliamperes of current were flowing in the circuit, a milliammeter with a full scale reading of 5 milliamperes or perhaps 10 milliamperes would be used, and a partial deflection would be obtained on the meter. The calibrated scale on the meter would then be read to determine the exact amount of current flowing in the circuit.

To briefly summarize this portion of the discussion it can be said that current is the progressive flow of the free electrons around a circuit. Current will flow only when the electrons are being pushed, or forced, around the circuit by the electromotive force (voltage) which is applied to the circuit. Current is measured in amperes, milliamperes or microamperes.

Resistance

Resistance is a measure of the opposition the electrons encounter in flowing through a circuit. If a voltage is applied to the two ends of a piece of wire, current will flow through the wire. This current is made up of many free electrons bounding from one atom to another in a steady procession as explained previously. Instead of skipping neatly from one atom to the next, however, the electrons follow irregular paths as they "drift" along a piece of wire. If a piece of wire with a very small diameter is used the electrons encounter a "congested traffic condition" within the small wire. In other words, a considerable amount of opposition is offered to the flow of the free electrons. If a piece of special resistance material, carbon for example, is connected in the circuit, the opposition offered to the free electron flow (current) is high because most of the atoms in the carbon are holding their electrons tightly in their orbits and there are few free electrons present. In this case, we might consider our "congested traffic conditions" due to so many "parked" electrons.

Another analogy which illustrates the subject of resistance quite well is a bucket brigade fighting a fire. A person at the head of the line in the bucket brigade dips buckets of water out of a well and starts passing them along the line. The man at the other end of the line, of course, throws the water on the fire. If the line is working efficiently, the buckets of water are passed down the line rapidly and easily and the volume of water thrown on the fire is considerable. This might be compared in an electrical sense to a circuit with very low resistance since the current is passed through the circuit very efficiently. To illustrate an analogy similar to a circuit containing resistance, let us assume that the fire had been set by a mob which, after the bucket brigade had been set up, did not wish the fire to be extinguished. In this case the rioters would interfere with the persons attempting to pass the buckets of water down the line, and the result would be that only a small amount of water would ever be applied to the fire. In other words, the passage of the water along the bucket brigade encounters a lot of opposition. This is equivalent in an electrical circuit to resistance which opposes the flow of electrons.

It should be borne in mind at all times when considering d-c circuits that resistance is the opposition offered to the flow of current. Notice that voltage causes current to flow, whereas resistance opposes the flow of current. It might seem that it would always be desirable to have a circuit with as low a value of resistance in it as possible. However, this is not the case. In the great majority of the circuits used in radio and television equipment, resistors are inserted in the circuit for the particular purpose of opposing current flow. In other words when properly used, resistances are very necessary circuit components. Figure 6 illustrates some typical fixed resistors used in radio and television receivers.

The unit of resistance is the ohm. Resistors normally encountered in electronic circuits range in value from a few ohms to several million ohms. To make it possible to handle the large values of resistance more easily the terms kilohm and megohm are employed. The term kilohm is seldom used to show a value of resistance although its abbreviation is often used. For example a schematic diagram might show a 10K resistor, this is of course ten kilohms, but would normally be read "ten thousand." The term megohm is often encountered in radio and television circuits. One megohm is equal to one million ohms.

The Greek letter omega (Ω) is very often used in place of the word ohms. To illustrate: 100 Ω means 100 ohms; 5,000 Ω means 5,000 ohms, 5K Ω means 5,000 ohms; and 100K Ω means 100,000 ohms.

There is one thing which may cause some confusion when considering ohms in the value of thousands. As mentioned previously, the symbol K is normally used to indicate 1,000 ohms. However, in some cases the symbol M is used to indicate 1,000 when dealing with ohms. When M is used in this case it is usually a capitol M. Thus, 10M means 10,000 ohms.

In electronic formulas the letter R is used to indicate resistance. Thus, in the equation E = I x R, the R stands for resistance.

To briefly summarize this portion of the discussion it can be said that resistance is the opposition offered to the flow of an electric current in a circuit. The unit of resistance is the ohm, and the values encountered in electronics equipment range from a few ohms to several million ohms. The Greek letter omega (Ω) is often used as an abbreviation for the term ohm, the prefix K (or M) indicates 1000 and the term megohm indicates one million ohms. The letter R stands for resistance in electronic formulas.

Ohm's Law

In his experiments dealing with simple electrical circuits, about 120 years ago, the German scientist, George Simon Ohm discovered that a definite relationship exists between the voltage applied to a circuit, and the resistance in the circuit. This relationship is now called Ohm's Law. Since the understanding of all d-c circuits requires the intelligent use of Ohm's Law, the remaining portion of this assignment will consist of an explanation of this law and its uses. The Associate will use Ohm's Law from time to time as he progresses in the training program and will soon have a thorough understanding of it.

Before actually considering Ohm's Law let us consider a simple d-c circuit once more. As pointed out, the voltage applied to the circuit exerts a force on the electrons present in the circuit and will cause a movement of free electrons around the circuit if a complete circuit exists. In other words, the voltage causes current to flow in the circuit. However, the resistance present in the circuit opposes the flow of the current. Thus, the voltage attempts to cause the current to flow while the resistance attempts to keep it from flowing. It should be obvious that there is some relationship which exists between the amount of current which flows, the applied voltage, and the resistance present in the circuit. This simple relationship is Ohm's Law.

To illustrate the use of Ohm's Law a number of circuits will be shown in this assignment and problems associated with these circuits will be worked. It should be emphasized however, that the answers to the problems in this assignment are not important in themselves. The important thing in this assignment is that each and every answer must seem reasonable to you. The entire value of this assignment lies in the interest you take in finding out what happens and why it happens in an electrical circuit.

To illustrate Ohm's Law let us consider the simple circuits shown in Figure 7. George Ohm found that if he connected a simple circuit as shown in Figure 7(A), with a 1 volt battery and a 1 ohm resistor, 1 ampere of current would flow through the circuit. (Note that a calibrated scale is shown on the current meters in the various circuits of Figure 7 and the pointer on the meter indicates the current flowing in the circuit under the various conditions.) The schematic diagram of each of the various circuits is illustrated directly below the circuit. Notice in the circuit of Figure 7(A) that the 1 volt battery furnishes the electromotive force, or voltage, for the circuit. This emf exerts an electrical pressure on the electrons causing a current flow to occur. The path of this current flow is from the negative terminal of the battery, through the resistor, through the ammeter back to the positive terminal of the battery. Under the conditions illustrated in Figure 7(A) 1 ampere of current flows.

Now examine the circuit of Figure 7(B). Notice that the only difference between this circuit and the circuit of Figure 7(A) is the fact that a 1/2 ohm resistor has been installed in place of the one ohm resistor of the previous circuit. Notice, however, that changing the resistor in the circuit has changed the current which flows in the circuit. With the 1/2 ohm resistor in the circuit more current (2 amperes) flows in the circuit. Notice that the current flowing in the circuit is increased when the resistor is made smaller. Doesn't this seem logical to you when it is recalled that the resistance is the opposition offered to the current flow? With less opposition one would expect more current to flow in the circuit and that is exactly what happens. If this particular point is not clear to the Associate he should stop at this point and review the previous material before proceeding.

Figure 7(C) shows the condition which occurs when a 2 ohm resistor is used in the circuit, and the voltage is being produced by the same 1 volt battery as was done previously. Under these conditions only 1/2 ampere of current flows as illustrated by the calibrated scale on the meter shown in this figure.

Examine the circuits of Figure 7(A), (B) and (C) very carefully and then see if you agree with the following summary of the action taking place. For a given voltage applied to the circuit, the larger the resistance present in the circuit the smaller will be the amount of current flowing and, conversly, the smaller the resistance present in the circuit, the larger will be the current which flows.

Figure 7(A), (B) and (C) illustrate the action which occurs in a simple circuit when the value of <u>resistance</u> in the circuit is changed. To determine the effect produced by changing the value of <u>voltage</u> applied to the circuit compare Figure 7(A) and (D). The circuit of Figure 7(A) consists of a 1 volt battery and a 1 ohm resistor. However, in Figure 7(D) a 2 volt battery has been installed in the circuit in place of the 1 volt battery of the previous circuit. Notice that under these conditions a current of 2 amperes flows as illustrated by the meter in Figure 7(D). Note particularly, in comparing Figure 7(A) and (D), that the same resistance is employed in each case, but that a larger voltage is applied to the circuit of Figure 7(D). Under these conditions notice also that more current flows. Let us briefly summarize this action. For a given resistance in a circuit, <u>more</u> current will flow if the voltage is increased. This also seems quite logical when we recall that voltage is the electrical force or pressure in the circuit. If the pressure is increased with a constant opposition, (resistance) the current flow should, logically, increase.

Ohm wrote these conclusions in a simple mathematical formula which is written below.

$$\text{Current} = \frac{\text{Applied voltage}}{\text{Resistance}}$$

Let us now write this formula using the symbols mentioned previously. The formula would then appear as follows:

$I = \frac{E}{R}$ (Formula A)

I stands for current in amperes
E stands for electromotive force in volts
R stands for resistance in ohms

This formula may be used in radio and electrical circuits to determine the amount of current flowing in a circuit if the voltage and the resistance are known. By applying this formula the current which flows in a circuit can be determined without using a milliammeter or ammeter.

It is sometimes desirable to determine the amount of resistance present in a circuit if the voltage and the current are known. In this case the following formula, which we shall call Formula B, may be employed.

$R = \frac{E}{I}$ (Formula B)

The symbols of this formula have the same meaning as in (Formula A).

Under certain circumstances it is desirable to be able to determine the amount of voltage applied to a circuit if the current flowing in the circuit and the resistance of the circuit are known. In this case the following formula may be employed.

$E = I \times R$ (Formula C).

It should be emphasized that these three formulas are not three separate formulas but are merely the same formula rearranged in three different manners so that the quantity which it is desired to determine is on the left side of the equation. Formula A may be used to find the amount of current flowing when the voltage and amount of resistance of the circuit are known and the value of current is unknown. Formula B may be used to find the amount of resistance in a circuit when the voltage and current are known, and Formula C may be used to find the applied voltage when the current and resistance are known.

Let us apply these formulas to some specific circuits to illustrate their use. For example let us apply Formula A to the circuits of Figure 7(A), (B) and (C) assuming in each that the amount of voltage produced by the battery is known and the size of the resistor is as shown, but that for some reason or other the ammeter in each circuit could not be read.

In Figure 7(A) we have 1 ohm of resistance and a 1 volt battery. Let us solve to find the amount of current which would be flowing in this circuit. Remember:

I stands for current in <u>amperes</u>
E stands for electromotive force in <u>volts</u>
R stands for resistance in <u>ohms</u>

To solve this problem, we first write down the correct formula, then we substitute the known quantities in the equation and solve for the unknown. Since we desire to determine the current which flows in the circuit we will use Formula A.

$I = \frac{E}{R}$ (In this case E equals 1 volt and R equals 1 Ω.)

Putting these values in our formula we have:

$I = \frac{1}{1}$

I = 1 ampere (Answer)

Notice how simple it is to determine the amount of current flowing in the circuit if the applied voltage and the resistance are known, merely by applying Ohm's Law.

Assuming that the meter of Figure 7(B) could not be read let us solve the problem presented by this figure in the same manner.

$I = \frac{E}{R}$ (E equals 1 volt, R equals 1/2 Ω or .5 Ω.)

$I = \frac{1}{.5}$ $\left(.5 \overline{)1.0} = 2;\ 1.0 - 1.0 = 0 \right)$

I = 2 amperes (Answer)

Applying this same method of the circuit of Figure 7(C) we have:

$I = \frac{E}{R}$ (E equals 1 volt, R equals 2 Ω.)

$I = \frac{1}{2}$

I = 1/2 ampere (Answer)

Now let us consider a circuit involving a 2 volt battery, an ammeter, and a resistor, connected as shown in Figure 7(D). However, let us assume that the value of the resistor is unknown. Remember: The battery voltage is known to be 2 volts and the current is known to be 2 amperes. Formula B can be applied to determine the value of the resistance in the circuit.

$R = \frac{E}{I}$ (E equals 2 volts, I equals 2 amperes)

$R = \frac{2}{2} = 1\ \Omega$ (Answer)

Let us again make an assumption. In this case, let us assume that a circuit as shown in Figure 7(C) is arranged and a 2 Ω resistor is used. The ammeter indicates that 1/2 ampere of current flows in the circuit but the value of the battery voltage is assumed to be unknown. Formula C can be applied to determine the battery voltage.

$E = I \times R$ (I equals 1/2 ampere, R equals 2 Ω)

$E = 1/2 \times 2$

$E = 1$ volt (Answer)

You are strongly advised to work several more problems for yourself using the circuits shown in Figure 7(A), (B), (C) and (D). For example, assume that the voltage is unknown in the circuit of Figure 7(D) and determine the value of this voltage by applying the appropriate Ohm's Law formula when the values of resistance and current are known. Check your answer against the value of voltage indicated in the circuit of Figure 7(D). By making similar assumptions work several problems concerning these four circuits until you are certain that you understand the use of the various Ohm's Law formulas. To provide you with added practice in the application of Ohm's Law, three circuits are shown in Figure 8. Apply the appropriate Ohm's Law formula to each one of these circuits to find the unknown quantity. Be sure and work these problems to the best of your ability before checking your answers with those given at the end of the assignment.

Circuit Terminology

We will find as we progress in the subject of circuits that a number of different arrangements may be employed. There are three general circuit arrangements and these are called; series circuits, parallel circuits, and series-parallel circuits. However, before considering the various types of circuits, let us consider just what a circuit is, and what is meant by the terms closed circuit, open circuit, and short circuit.

By definition, a closed circuit or complete circuit is a complete path over which electrons can flow from the negative terminal of the voltage source through the parts and wires to the positive terminal of the same voltage source. Thus, any of the arrangements of Figures 7 or 8 would form a closed circuit or complete circuit. Note that for the circuit to be closed, or complete, a path must be provided for the electrons to flow from the negative terminal of the voltage source to the positive terminal of the same source.

An open circuit is a circuit which does not provide a continuous path for the electrons. Such a circuit is shown in Figure 9. Notice that the switch in this circuit is open. Under these conditions a complete path from the negative terminal of the voltage source is not provided through the parts and components to the positive terminal of the voltage source because the open switch will not pass electrons. Since a complete path is not provided in the circuit of Figure 9, no current will flow in the circuit. It is for this purpose that switches are connected in circuits. For example, in a normal house wiring circuit, switches are connected in series with the various lights. Thus in the day time the switch is turned off, or in other words, the switch is placed in an open position, and the electric light is not illuminated. However, when it is desired to have the light illuminated it is only necessary to close the switch which completes the circuit, thereby enabling the electric current to flow through the filament of the light bulb and produce the desired illumination.

There is one point which should be made clear concerning an open circuit. If a switch is connected in the circuit and is in the open position, an open circuit will be formed, However, open circuits may be formed by other means, for anything which will cause the path of the electrons to be broken, will form an open circuit. For example, in the simple circuit of Figure 5, if one of the leads were to become disconnected from the terminal on the dry cell an open circuit would be formed. Similarly an open circuit might be formed in the circuit of Figure 5 by a defective ammeter, or perhaps by a lead breaking off the resistor. Thus, it should be borne in mind that an open circuit may result from a number of different causes.

The third circuit characteristic mentioned previously is the short circuit. By definition, a short circuit is a low resistance connection across a voltage source or between both sides of a circuit, usually accidental, which in most cases, results in excessive current flow that may cause damage. A short circuit is illustrated in Figure 10. Notice that in this case the lead coming from the positive terminal and the one from the negative terminal of the battery are accidentally touching. Thus a low resistance path is provided from the negative terminal of the battery around to the positive terminal and the current may follow this path instead of flowing through the resistor and meter as it should. The touching of the two wires is called a short circuit, or in some cases just a "short". Such a condition would in this case ruin the battery in very short order. In other circuits a short circuit may ruin other components such as meters, etc. Since short circuits are very undersirable, insulated wire is employed in most electrical circuits. For example, insulated wire is used in radio and television receivers, insulated wire is used in house wiring circuits, in automobile ignition circuits, etc.

Now that the characteristics of circuits have been considered let us analyze the three fundamental types of circuits, the series circuit, the parallel circuit and series-parallel circuit.

Series Circuits

A series circuit is a circuit which is so arranged that all of the current which flows from the negative terminal of the voltage source passes through each component in the circuit and returns to the positive terminal of the voltage source. Two simple series circuits are illustrated in Figure 11. The path followed by the current in each case is illustrated by the dotted line. Notice in Figure 11(A) that the current leaves the negative terminal of the battery, flows through the resistor, through the meter, and finally returns to the positive terminal of the battery. The schematic diagram of the circuit is also shown. Thus, in the circuit of Figure 11(A) the resistor and meter are connected in series across the battery as all of the current flows through each of these components. Similarly in Figure 11(B) the current path indicates that the electrons flow through the meter and then through the resistor to return to the battery. Thus, the meter and the resistor are in series in this case. These circuits also illustrate the proper way to use a milliammeter to measure current in a circuit. The milliammeter is connected in series with the circuit.

Another factor which is illustrated by the circuits of Figure 11 is the fact that the milliammeter can be connected at any point in a series circuit. If the same size battery and resistor are employed in the circuits of Figure 11(A) and (B) the current flow as indicated by the meter in the two cases will be the same. The reason for this is that the current is the same at all points in a series circuit. The same amount of current that leaves the negative terminal of the battery re-enters the positive terminal of the battery. In the circuits of Figure 11 the same amount of current flows through the conductor connecting the negative terminal of the battery to the resistor as flows through the resistor. This current is also equal to the current flowing through the meter. By following this line of reasoning it should become clear to the Associate that the meter can be connected either as shown in Figure 11(A) or (B) to indicate the amount of current flowing in the circuit.

To further illustrate the action of a series circuit consider the circuit illustrated in Figure 12(A). This circuit consists of a 1 1/2 volt battery, a switch, a 500 ohm resistor and a milliammeter. In this circuit four meters are illustrated. The milliammeter is connected in series with the circuit to indicate the current which flows. In addition, a voltmeter is shown connected across the battery, another voltmeter is shown connected across the switch and a third voltmeter is connected across the resistor.

This circuit illustrates several points. One of the points illustrated is the proper way to connect meters. As may be noted the milliammeter is connected in series with the circuit as illustrated in Figure 11 and should require no further explanation. The manner in which the three voltmeters are connected illustrates the proper way to use such an instrument. One voltmeter is connected across the battery. That is, one lead of the voltmeter is connected to the positive terminal of the battery and the other lead of the voltmeter is connected to the negative terminal. When connected in this manner the voltmeter will indicate the emf of the battery in volts. The voltmeter to measure the voltage applied to the switch is connected across the switch, and the voltmeter to measure the voltage applied to the resistor is connected across the resistor.

The following summarizes the proper manner in which meters should be connected: An ammeter or milliammeter should be connected in series with the circuit; Voltmeters should be connected across a component.

Let us look at the circuit of Figure 12(A) carefully, noting particularly the reading on the meters. The voltmeter connected across the battery reads the emf produced by this battery which is 1.5 volts. Notice also that although the milliammeter is connected properly, (in series with the circuit), there is no current flow indicated by the meter. The reason for this is the fact that the switch is open. As mentioned previously the open switch forms an open circuit and there is no complete path from the negative terminal of the battery around to the positive terminal. Since there is no complete path, current cannot flow.

Now notice the readings of the voltmeters at the various points in the circuit of Figure 12(A). The voltmeter connected across the battery indicates 1 1/2 volts which is the emf produced by the battery. The voltmeter connected across the switch also indicates 1 1/2 volts whereas the voltmeter across the resistor indicates zero. As mentioned the switch forms an open circuit and the entire voltage present in the circuit is applied across this switch attempting to force current through the switch. This accounts for the 1 1/2 volt reading obtained on the voltmeter connected across the switch. However, since no current flows in the circuit there will be zero voltage across the resistor in the circuit.

Now examine Figure 12(B). It will be noted that this is the same as the circuit of Figure 12(A) except that the switch has been closed. When the switch is closed a complete circuit is formed, current flows in the circuit, and an entirely different condition exists than that of Figure 12(A). In the circuit of Figure 12(B) the milliammeter tells us that 3 milliamperes (.003 amperes) of current is flowing through the circuit. The voltmeter across the 500 ohm resistor now reads 1 1/2 volts. This meter tells us that 1 1/2 volts of electrical pressure are being used to force the 3 milliamperes of current through the 500 ohm resistor.

The voltmeter connected across the switch now reads zero. There is practically no resistance between the two terminals of the switch when the blade is closed. No voltage is needed to force the 3 milliamperes of current through the closed switch.

The voltmeter at the cell still reads 1 1/2 volts, and the voltmeter connected across the resistor now reads 1 1/2 volts also. The question naturally arises: Do we now have 3 volts in the circuit? The answer is a very definite: No! The voltage of the dry cell is the source voltage and the voltage appearing across the resistor is commonly called a voltage drop. Voltage drop is the term applied to the voltage which is applied across a particular component, such as a resistor, which causes current to flow through that particular component. In this particular case, the voltage drop across the 500 ohm resistor is equal to the voltage source as all of the voltage in the circuit appears across the 500 ohm resistor causing the current of 3 milliamperes to flow through this resistor. The subject of voltage drops will be taken up in greater detail presently in this assignment.

In the circuit of Figure 12(B) the value of the resistance is known and the current and voltage present in the circuit are indicated by the meters in the circuit. In this circuit, as in many others however, we would not need the large number of meters indicated to determine voltage and current. We can use Ohm's Law.

The cell develops 1 1/2 volts of electrical pressure. E therefore is 1 1/2 volts. The total resistance in the circuit is 500 ohms; Therefore, R is 500 ohms.

To determine how much current would flow in the circuit of Figure 12(B) without the use of a milliammeter, we can use the formula that tells us:

$$I \text{ (current in amperes)} = \frac{E \text{ (Voltage in volts)}}{R \text{ (Resistance in ohms)}}$$

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

$$I = \frac{1.5}{500}$$

I = .003 ampere or 3 milliamperes.

Thus it can be seen that in the circuit of Figure 12(B) Ohm's Law can be used to determine the current which would flow if a 500 ohm resistor were connected across a 1 1/2 volt battery.

To further demonstrate the use of Ohm's Law in series circuits consider the circuits of Figure 13. In Figure 13(A) is shown a circuit consisting of a 7 1/2 volt battery, a milliammeter, a 5,000 ohm resistor and a switch. It will be noted that this is also a series circuit as only one path is provided for the current. The milliammeter in the circuit indicates that 1.5 milliamperes of current flows under these conditions. However, the amount of current flowing in this circuit could be determined without the use of a milliammeter merely by the proper application of Ohm's Law. The voltage is 7 1/2 volts in the circuit and the resistance is 5,000 ohms. The current can be determined as follows:

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

$$I = \frac{7.5}{5000}$$

I = .0015 ampere or 1.5 ma.

In Figure 13(B) we have a circuit consisting of a 100 volt battery, a milliammeter, a 50,000 ohm resistor, and a switch. The milliammeter indicates that 2 milliamperes of current will flow in the circuit. Let us check this by the application of Ohm's Law.

$$I = \frac{E}{R}$$ (In this case E equals 100 volts and R equals 50,000 ohms.)

$$I = \frac{100}{50,000}$$

I = .002 ampere or 2 ma.

Notice that in our Ohm's Law problems we must always use the whole units; volts, ohms and amperes. If we care to we may change our answers to smaller units, as we did in this example, but in the solution of the problem we must use the fundamental units.

Figure 13(C) shows a circuit consisting of a 50 volt battery, an unknown value of resistance, and the milliammeter in the circuit indicates that 10 milliamperes of current is flowing. Let us apply Ohm's Law and find the unknown value of this resistance. The formula we will use in this case is: $R = \frac{E}{I}$ since we desire to determine the resistance in the circuit. Note: we must change the milliamperes to amperes before using the value of current in our formula. If 1 milliampere of current equals .001 ampere then 10 milliamperes equals 10 x .001 or .010 ampere.

$$R = \frac{50}{.010}$$

R = 5,000 ohms

Notice that in this example Ohm's Law demonstrates the fact that if 10 milliamperes of current flows in a circuit connected to a 50 volt battery, the value of resistance present in the circuit must be 5,000 ohms.

To further illustrate the use of Ohm's Law consider the circuit of Figure 13(D) which consists of a battery, a 20,000 ohm resistor and a milliammeter which indicates a current of 2 milliamperes flowing in the circuit. Although the value of the battery voltage is unknown, Ohm's Law can be applied to determine the voltage. Since the voltage is the unknown in this case we will use the formula E = I x R.

E = I x R (2 milliamperes equals .002 amperes)

E = .002 x 20,000

E = 40 volts

The Ohm's Law calculation just completed indicates that if 2 milliamperes of current flow through a circuit containing 20,000 ohms of resistance, the applied voltage must be 40 volts.

The circuits we have been discussing so far are series circuits. A series circuit is one in which there is only one path for the current to follow through the circuit. However, the circuits which we have been discussing have had only one resistor present although it is possible for a series circuit to contain several resistors. Figure 14 shows a circuit consisting of a 40 volt battery, a milliammeter and two 10,000 ohm resistors, all connected in series. The current path is indicated in this circuit and it can be seen that after leaving the negative terminal of the battery the electrons must flow through the milliammeter, then through the resistor labeled R_1, then through the resistor labeled R_2, then through the switch, finally returning to the positive terminal of the battery. Thus it can be seen that the resistors are in series since the current must flow through each of them. If each of these resistors offers 10,000 ohms of resistance, the current first encounters an opposition equal to 10,000 ohms and then encounters another opposition equal to 10,000 ohms. The total resistance is then 10,000 plus 10,000 or 20,000 ohms. The current flowing in the circuit is indicated to be 2 milliamperes by the milliammeter but could be determined if the milliammeter were not available. To do this we would apply Ohm's Law.

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

(Remember the total resistance in the circuit is 20,000 ohms.)

$$I = \frac{40}{20,000}$$

$$I = .002 \text{ amperes or } 2 \text{ ma}$$

Now let us consider the voltage drops in this circuit. As the current follows the path indicated by the dotted line in Figure 14, it flows first from the negative terminal of the battery through the milliammeter, then through R_1, R_2, the switch, and finally returns to the positive pole of the battery. As the current flows through the various components in the circuit, voltage drops are produced across the components. However, since the resistance of the milliammeter and the closed switch are so small, they can be neglected for this discussion and we will consider the two voltage drops across R_1 and R_2. The polarity of the voltage present across each of these resistors is indicated in Figure 14. There is a very simple way in which the polarity of voltage drops in a series circuit can be determined. This can be done in tracing the current path from the negative terminal of the battery around through the circuit and back to the positive terminal of the battery. The polarity of the voltage drops across each resistor will be such that the end of the resistor that the current enters will be the negative end. Check the polarity of the voltage drops in Figure 14 to make sure that you understand this point.

Let us determine the value of the voltage drop across each resistor in the circuit of Figure 14. Our previous calculations have indicated that the current flowing in the circuit is 2 milliamperes, or .002 ampere. This current flows through R_1 which is a 10,000 ohm resistor. We may then apply Ohm's Law to determine the amount of voltage present across R_1.

$$E = I \times R$$

$$E = .002 \times 10,000$$

$$E = 20 \text{ volts}$$

This is the amount of voltage drop present across R_1. Since R_2 is also a 10,000 ohm resistor through which 2 milliamperes of current is flowing there will be a 20 volt drop across this resistor also. This circuit illustrates another important point concerning voltage drops. In any series circuit the sum of the voltage drops is equal to the source voltage. In this particular case the source voltage is 40 volts and the sum of the voltage drops is equal to the voltage drop across R_1 plus the voltage drop across R_2, or 20 plus 20 equals 40 volts.

Let us now connect several resistors in series in a similar circuit. Let us assume that we have the filaments of four tubes connected in series. (The filament of a tube is actually a special type of resistor.) Such a circuit is illustrated in Figure 15. Each filament has a resistance of 21 ohms. Checking the current path in the circuit of Figure 15 will indicate that after leaving the negative terminal of the battery and passing through the ammeter the current flows first through filament No. 1, then filament No. 2, then filament No. 3, and finally through filament No. 4 to the positive terminal of the battery. Thus if each of the filaments offers an opposition to the flow of current equal to 21 ohms, we have a total of 4 x 21 or 84 ohms of resistance in this circuit.

The ammeter in the circuit will read .3 ampere. This can be determined by the application of Ohm's Law.

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

(E is the total voltage of 25.2 V and R is the total resistance of 84 Ω.)

$$I = \frac{25.2}{84}$$

$$I = .3 \text{ ampere}$$

Since there are four resistors in the circuit of Figure 15 there will be four voltage drops. The polarity of each of these voltage drops is indicated in Figure 15 and you are advised to check the direction of the current flow and determine whether or not you agree with the polarity of each voltage drop indicated.

Let us now determine the amount of voltage across each filament. The current flowing through the circuit is .3 ampere and the resistance of each filament is 21 ohms. Thus Ohm's Law can be applied to determine the amount of voltage present across each resistor as follows:

$$E = I \times R$$

$$E = .3 \times 21$$

$$E = 6.3 \text{ Volts Per Filament}$$

Since the filaments have equal resistance there will be 6.3 volts across each filament. Thus, the voltmeters shown connected across each of the filaments in the circuit of Figure 15 would each read 6.3 volts.

In Figure 15 we have one voltmeter connected so as to indicate the voltage applied across two of the filaments--filament No. 3 and filament No. 4. This voltmeter would read 12.6 volts. We can check this reading by Ohm's Law. The total resistance of two of the 21 ohm filaments is 2 x 21 = 42 ohms. The current flowing through the circuit is .3 ampere. Thus:

$$E = I \times R$$

$$E = .3 \times 42$$

$$E = 12.6 \text{ volts}$$

A point which has been mentioned previously which can be illustrated clearly by the circuit of Figure 15 is the fact that the current is the same at all points of a series circuit. This is true because the same current flows through each component in the circuit. Thus in the circuit of Figure 16, (You will recognize this circuit as being the same as Figure 15), the ammeter will indicate .3 ampere with the meter connected at the points indicated in any of the circuits shown in this Figure. Similarly the ammeter could be connected between the negative terminal of the battery and the "string" of filaments.

In Figure 15 the total resistance of the 4 filaments, or resistances, in series was the sum of these 4 resistances, or 21 + 21 + 21 + 21 = 84 ohms. These four resistors could be replaced by one 84 ohm resistor which would cause the same amount of current to flow as the four series filaments cause. The value of resistance which could be used to replace several resistors, and still have the same current flow in the circuit, is called the equivalent resistance. In this example the equivalent resistance, of the four filaments in series, is 84 ohms. The equivalent resistance of series resistors is the sum of the various resistors. Stated mathematically this is:

$$R_t = R_1 + R_2 + R_3 + R_4 + \text{etc.}$$

In this formula R_t stands for the equivalent or total resistance.

Applying this formula to Figure 15 we would have:

$$R_t = R_1 + R_2 + R_3 + R_4$$

$$R_t = 21 + 21 + 21 + 21$$

$$R_t = 84 \text{ ohms.}$$

Figure 17 shows a circuit consisting of three resistors connected in series across a 30 volt battery. Let us determine the equivalent resistance, or in other words the total resistance, of these three resistors. This can be done by applying the formula used in the preceding example.

$$R_t = R_1 + R_2 + R_3$$

$$R_t = 5{,}000 + 10{,}000 + 15{,}000$$

$$R_t = 30{,}000\ \Omega$$

Thus the total opposition offered by the three resistors in the circuit of Figure 17 is 30,000 ohms. The amount of applied voltage is 30 volts as indicated in the schematic diagram. Thus Ohm's Law can be used to determine the amount of current which will flow in the circuit. We will use the formula:

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

$$I = \frac{30}{30{,}000}$$

$$I = .001 \text{ ampere or } 1 \text{ ma.}$$

Thus our computations have indicated that 1 milliampere of current flows from the negative terminal of the battery through the 5,000 ohm resistor, through the 10,000 ohm resistor, through the 15,000 ohm resistor, then through the milliammeter to the positive terminal of the battery. As mentioned previously, the current flowing through the series circuit will cause voltage drops to appear in the circuit and since we know the current which flows through each resistor and the ohmic value of the resistor, the value of each voltage drop can be computed. Before proceeding with the following calculations see if you can determine the amount of voltage drop across each resistor.

Ohm's Law states: E = I x R. The voltage drop across a particular resistor is equal to the current through that resistor times the ohmic value of that resistor.

To find the voltage drop across R_1:

$$E = I \times R$$

(The current is 1 milliampere and the resistance of R_1 is 5,000 ohms.)

$$E = .001 \times 5000$$

$$E = 5 \text{ volts}$$

Note: This is the voltage drop across resistor R_1.

To find the voltage drop across R_2:

$E = I \times R$ (The current is still 1 milliampere and the resistance of R_2 is 10,000 ohms.)

$E = .001 \times 10,000$

$E = 10$ volts — Note: This is the voltage drop across resistor R_2.

To find the voltage drop across R_3:

$E = I \times R$ (The current is still 1 milliampere and the resistance of R_3 is 15,000 ohms.)

$E = .001 \times 15,000$

$E = 15$ volts. — Note: This is the voltage drop across resistor R_3.

The preceding calculations have indicated the amount of voltage drop present across each of the three resistors in the circuit of Figure 17. By tracing the current path as indicated in this figure the polarity of the voltage drops can also be determined. This is shown by the plus and minus signs associated with each resistor in the circuit. (Remember the end of a resistor which the current enters is the negative end of the voltage drop produced across that resistor.)

The total of the voltage drops in the circuit of Figure 17 can be found by adding the three individual voltage drops or, 5 volts + 10 volts +15 volts = 30 volts. Thus it can be seen that the total of the voltage drops in the circuit equals the voltage source as mentioned previously.

Many of the circuits in electronic and television equipment consist of series circuits similar in nature to the one shown in Figure 17. Of course, the voltage may be supplied by a power supply instead of the battery indicated in this figure, but for practical purposes, the operation of the circuits are similar. For this reason, the Associate should have a thorough understanding of series circuits. Although this understanding can be obtained by merely reading the assignment material, it is advisable for the Associate to carry the process further by analyzing series circuits very carefully and working Ohm's Law problems. It is for this purpose that Figure 18(A) and (B) are shown. Notice that in each case a series circuit is illustrated and the things which should be found out about the circuit are indicated. Work the problems presented by each of these circuits very carefully applying the procedures which have been outlined previously. Then, after you have worked these problems to the best of your ability, refer to the solutions given at the end of this assignment to check your work. In this way you will be able to obtain a complete understanding of the operation of series circuits and Ohm's Law.

Parallel Circuits

Up to this point we have considered series circuits only. These are circuits in which there is only one path for the current. Another type of circuit is the parallel circuit. A parallel circuit is a circuit that provides two or more paths for the current.

Figure 19 illustrates a simple parallel circuit. Notice that two resistors are connected to the battery but these resistors are not in series since the same current which flows through one does not flow through the other. In the schematic diagram of this circuit, also illustrated in Figure 19, the two current paths provided by the parallel circuit are indicated. Notice that one path is provided for the current from the negative terminal of the battery through resistor R_1 back to the positive terminal of the battery. Likewise another path is provided from the negative terminal of the battery through resistor R_2 and back to the positive terminal. Thus this circuit provides two paths for the current. Such a circuit is called a parallel circuit.

Figure 20 illustrates another parallel circuit in which there are four parallel resistors. That is resistors R_1, R_2, R_3, and R_4 provide four paths for the current as illustrated in the schematic diagram of Figure 20. As would be expected from the fact that the current paths in the parallel circuit are entirely different from the current path in a series circuit, the operation of a parallel circuit is entirely different from the operation of a series circuit. The manner in which a parallel circuit operates will be considered in detail in a later assignment. This type of circuit is shown at the present time only to illustrate the various types of arrangements possible.

The Series-Parallel Circuit

The third general type of circuit is the series-parallel circuit. As indicated by the name of this type of circuit, a series-parallel circuit consists of a combination of series and parallel circuits. Such a circuit is illustrated in Figure 21. Notice in this figure that the current leaving the negative terminal of the battery flows through resistor R_1 until it reaches the point at which resistors R_2 and R_3 are connected together. At this point two paths are provided for the current, part of the current flowing through R_2 and the remaining portion of the current flowing through resistor R_3. The two portions of the current then combine once more at the junction of resistors R_2 and R_3 and the total current returns to the battery. In this circuit the combination formed by resistors R_2 and R_3 forms a parallel circuit as two paths are provided for the current. However, this parallel circuit is in series with the resistor R_1. After analyzing the circuit of Figure 21 it can be seen that a thorough understanding of a series-parallel circuit requires the understanding of the operation of a parallel circuit. Since parallel circuits will not be taken up at this time, the series-parallel circuit cannot be explained in detail. However, the series-parallel circuit shown in Figure 21 should illustrate to the Associate a number of possible ways in which a circuit can be arranged.

Summary

This assignment has demonstrated the manner in which d-c circuits operate. The relationship between voltage, current and resistance is a definite factor and conforms to the operations known as Ohm's Law. When two of these factors are known, the third can be found by applying Ohm's Law. The three Ohm's Law formulas are:

For finding the current: $I = \frac{E}{R}$

For finding the resistance: $R = \frac{E}{I}$

For finding the voltage: $E = I \times R$

In these formulas I stands for current in amperes, E stands for voltage in volts, R stands for resistance in ohms.

There are three types of circuit arrangements which will be encountered. These are: series circuits, parallel circuits, and series-parallel circuits. The manner in which a circuit arrangement can be identified is by checking the current path. If the same current flows through each component in the circuit the arrangement is a series circuit. If two or more paths, or branches, are provided for the current, the circuit is a parallel circuit. If the current flows through one or more components and then branches before completing its path the circuit arrangement is a series-parallel circuit.

In a series circuit the term equivalent resistance is used to indicate a resistance which could be inserted in the circuit in place of the various series resistors and cause the same current flow in the circuit. The equivalent resistance of series resistors can be found by applying the formula:

$$R_t = R_1 + R_2 + R_3 + R_4 + \text{etc.}$$

In other words, the equivalent resistance of series resistors is equal to the sum of the individual resistors.

The importance of having a thorough understanding of the operation of d-c circuits and the application of Ohm's Law cannot be overemphasized. All electronic circuits contain sources of voltage, and resistances; therefore, current flows. In many actual electronic and television circuits, two of these electrical quantities will be known and it will be necessary to apply Ohm's Law to find the third. For this reason, you are advised to review this assignment several times as you progress in the training program. Also, when you encounter the application of Ohm's Law in the future assignments and any question arises in your mind, you should refer to this assignment to clarify the condition. It is also a very good plan to practice drawing the various types of circuits as you encounter them.

For example, after you have completed your work on the portion of the assignment dealing with series circuits, draw several series circuits on a sheet of scratch paper and then compare your drawings with those of the series circuits in the assignment. In this manner you will become more familiar with the various types of circuits as you encounter them.

Answers To Exercise Problems

Problems Presented By Circuits Of Figure 8

Problem 8(A) I = 5 amperes. This answer is obtained as follows:

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

$$I = \frac{10}{2}$$

$$I = 5 \text{ amperes}$$

Problem 8(B) R = 20 ohms as found by the following calculations:

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

$$R = \frac{100}{5}$$

$$R = 20\ \Omega$$

Problem 8(C) E = 40 volts as found by the following calculations:

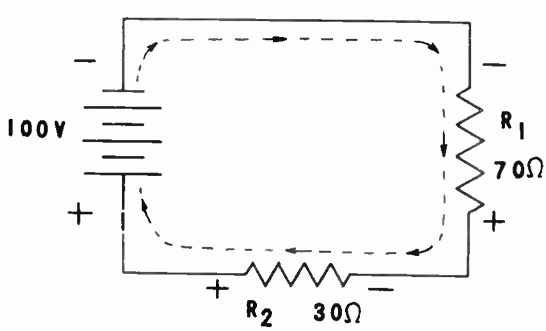
$$E = I \times R$$

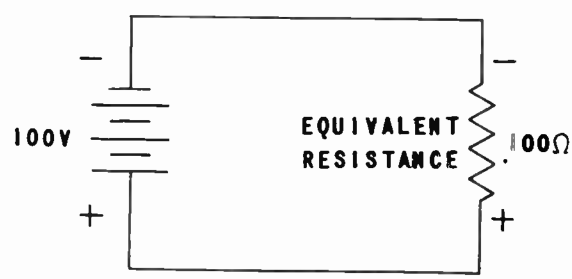
$$E = 4 \times 10$$

$$E = 40 \text{ volts.}$$

Problems Presented By Circuits Of Figure 18

Problem 18(A)





R Equiv. = $R_1 + R_2$ = 70 + 30

R Equiv. = 100 Ω

$$I = \frac{E}{R \text{ Equiv.}} = \frac{100}{100} = 1 \text{ ampere}$$

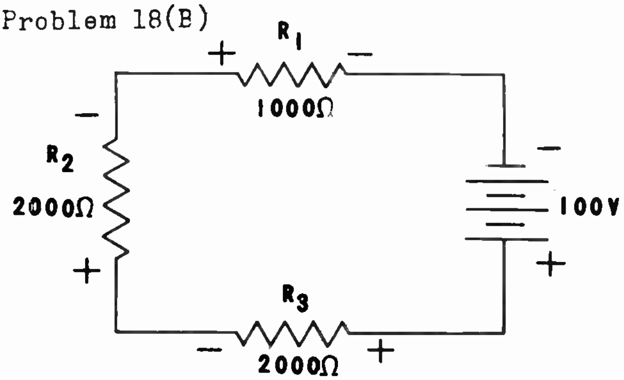
$E_{R_1} = I \times R_1 = 1 \times 70$

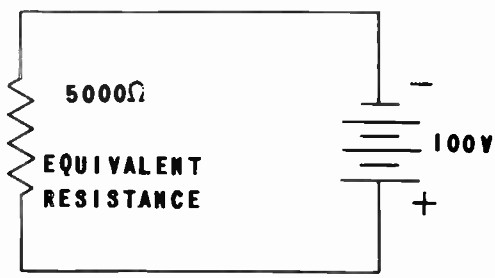
E_{R_1} = 70 volts

$E_{R_2} = I \times R_2 = 1 \times 30$

E_{R_2} = 30 volts

Problem 18(B)





R Equiv. = $R_1 + R_2 + R_3$ = 1000 + 2000 + 2000
R Equiv. = 5000 Ω

$$I = \frac{E}{R \text{ Equiv.}} = \frac{100}{5000}$$

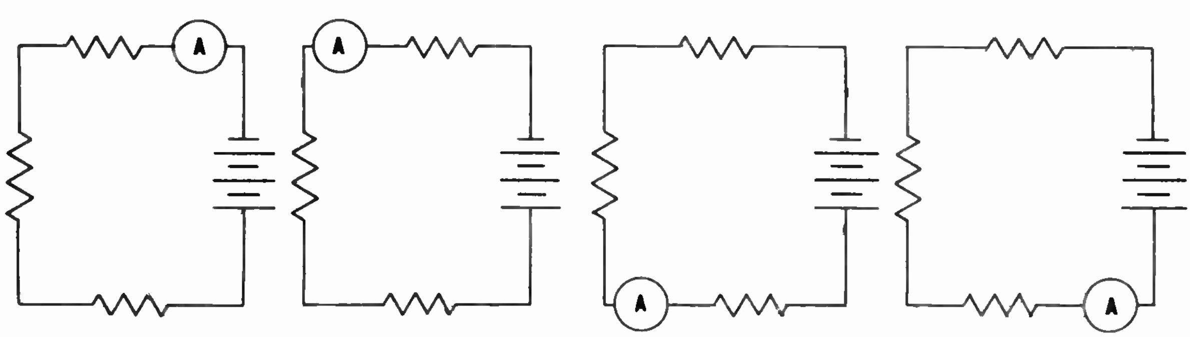
I = .02 ampere

$E_{R_1} = I \times R_1 = .02 \times 1000$
E_{R_1} = 20 volts

$E_{R_2} = I \times R_2 = .02 \times 2000$
E_{R_2} = 40 volts

E_{R_3} = 40 volts since R_3 is the same value as R_2.

Four Ways of Connecting Milliammeter In Circuit



Test Questions

Be sure to number your Answer Sheet Assignment 6.
Place your Name and Associate Number on every Answer Sheet.
Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

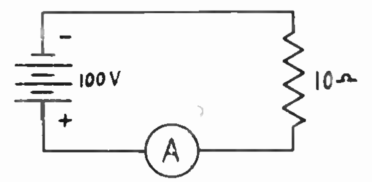
1. Is the current flowing in a circuit measured in: (a) amperes, (b) volts, or (c) ohms?

2. (a) What factor in an electrical circuit causes current to flow?
(b) In an electrical circuit what factor opposes the flow of the current?

3. (a) What term is used to indicate one million ohms?
(b) What term is used to represent one thousandth ampere?

4. List the three forms of Ohm's Law.

5. In the accompanying diagram how much current would be indicated by the ammeter? (Solve by Ohm's Law and show your work.)

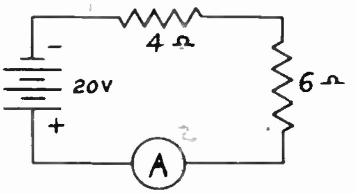


6. Explain the difference between an open circuit, and a closed circuit or complete circuit.

7. If an Ohm's Law problem gave a current value of 5 ma. to what should it be changed before working the problem?

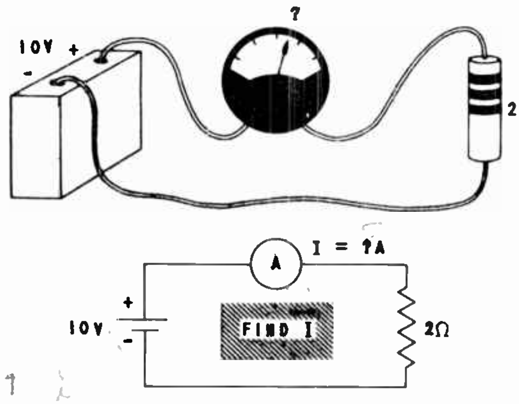
8. In a series circuit is the current the same in all parts of the circuit?

9. (a) In the accompanying circuit diagram what is the equivalent resistance of the two resistors in series?
(b) How much current would be indicated by the ammeter in this circuit?

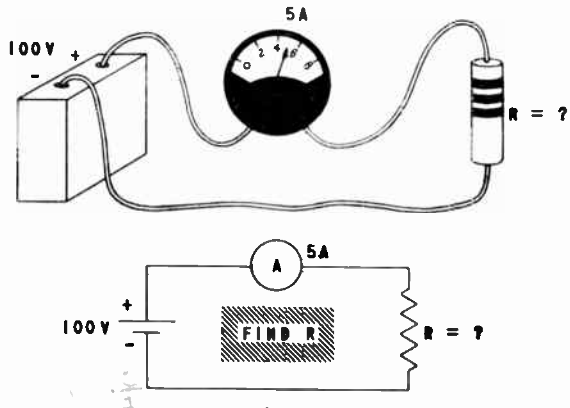


10. (a) On your Answer Sheet redraw the circuit of Question 9 indicating by means of a dotted line with arrow heads the direction of the current flow in the circuit. Also indicate by means of (+) and (-) signs the polarity of the voltage drop across each resistor. Also indicate the amount of voltage present across each resistor and show how a voltmeter would be connected to measure the voltage drop across the 4 ohm resistor.

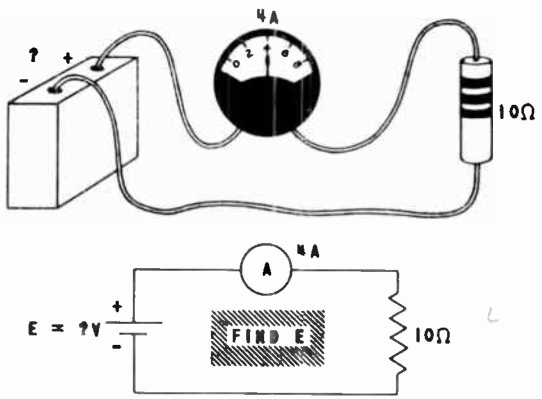
CIRCUITS FOR OHM'S LAW PROBLEMS



(A)



(B)



(C)

FIGURE 8

OPEN CIRCUIT

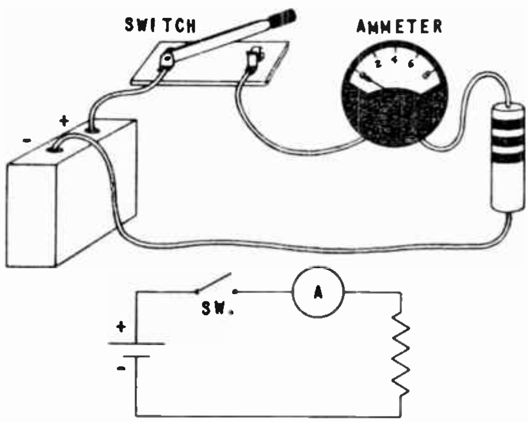


FIGURE 9

SHORT CIRCUIT

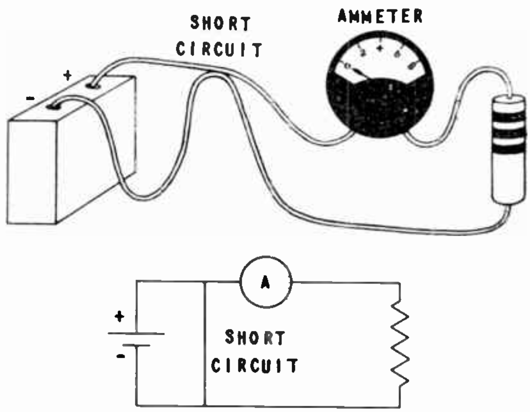


FIGURE 10

MEASURING CURRENT IN A CIRCUIT

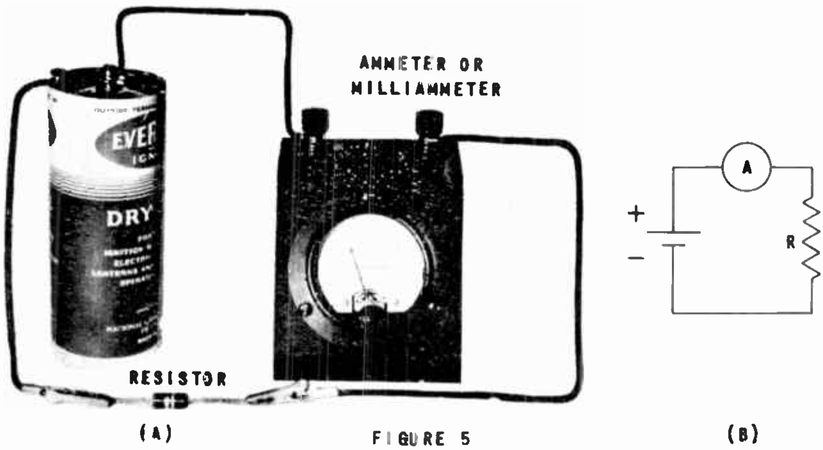
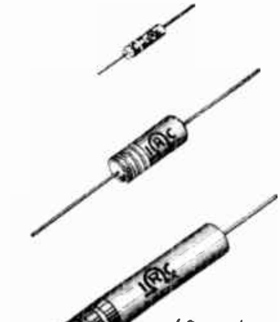


FIGURE 5

SOME TYPICAL FIXED RESISTORS



(Courtesy International Resistance Co.)

FIGURE 6

OHM'S LAW DEMONSTRATION

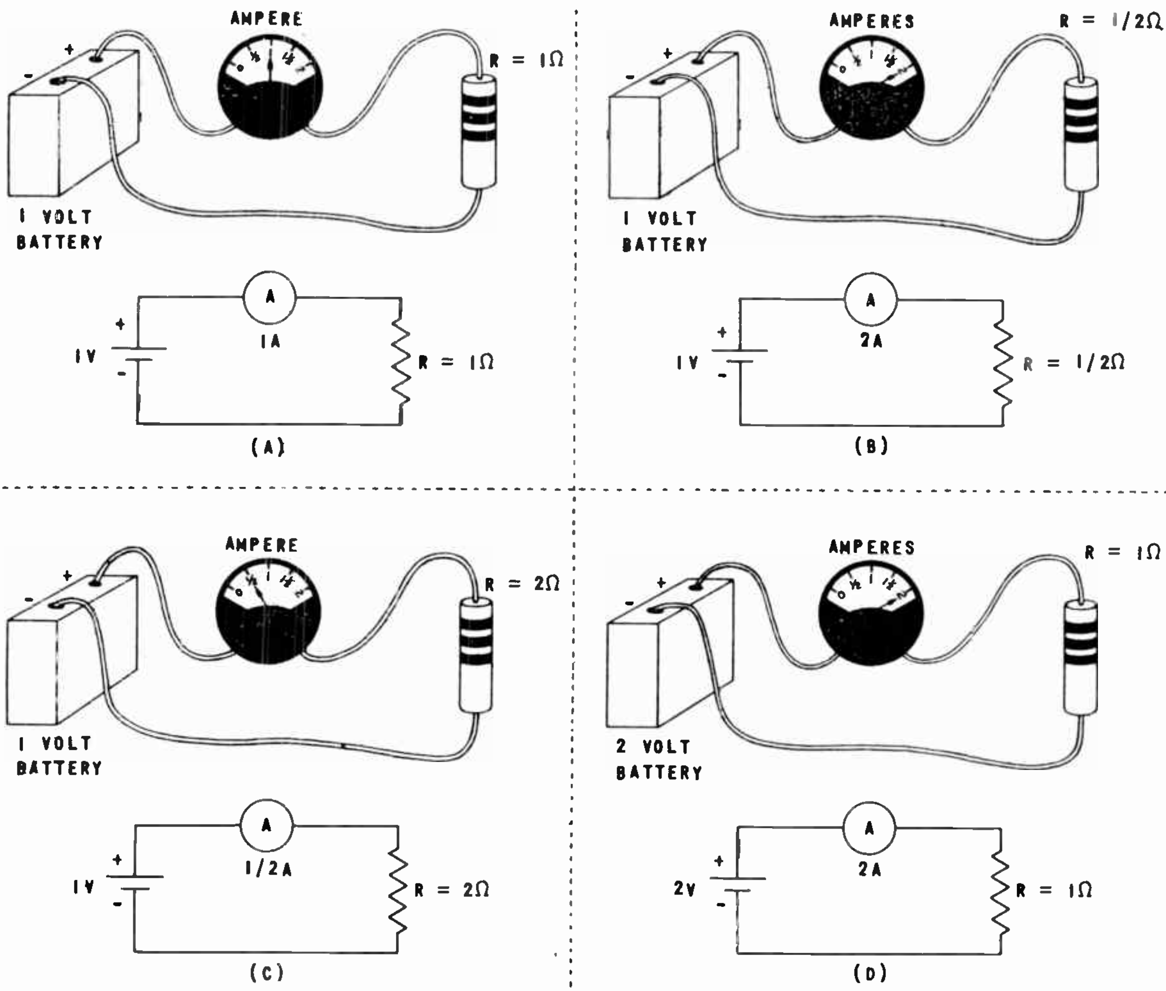


FIGURE 7

SIMPLE SERIES CIRCUITS ILLUSTRATING CURRENT PATHS

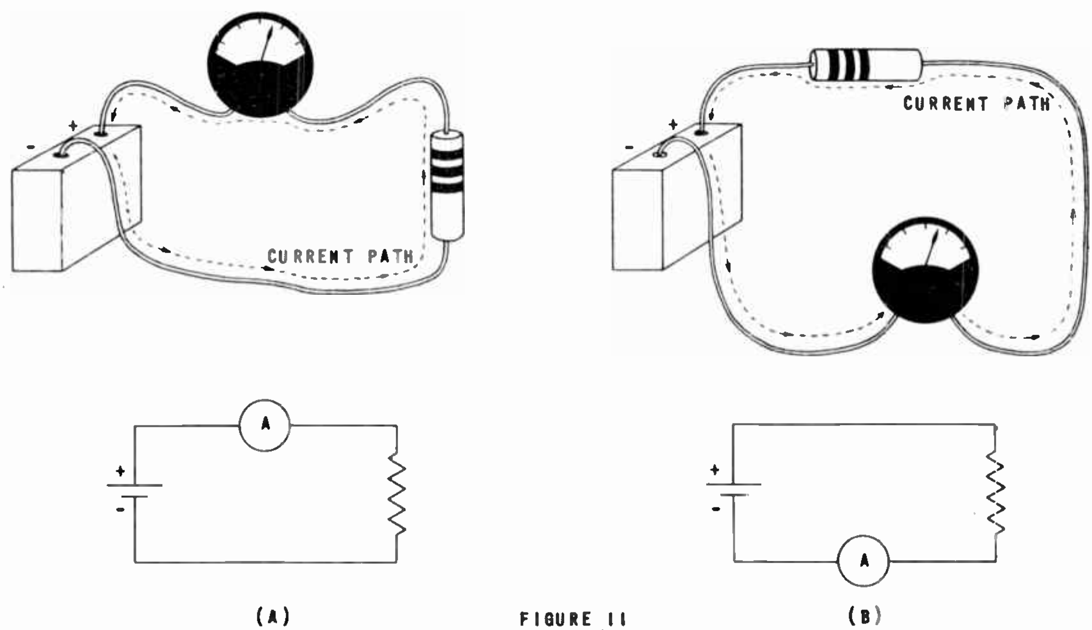


FIGURE 11

DEMONSTRATING ACTION OF A SWITCH AND PROPER METHOD OF CONNECTING METERS IN A CIRCUIT

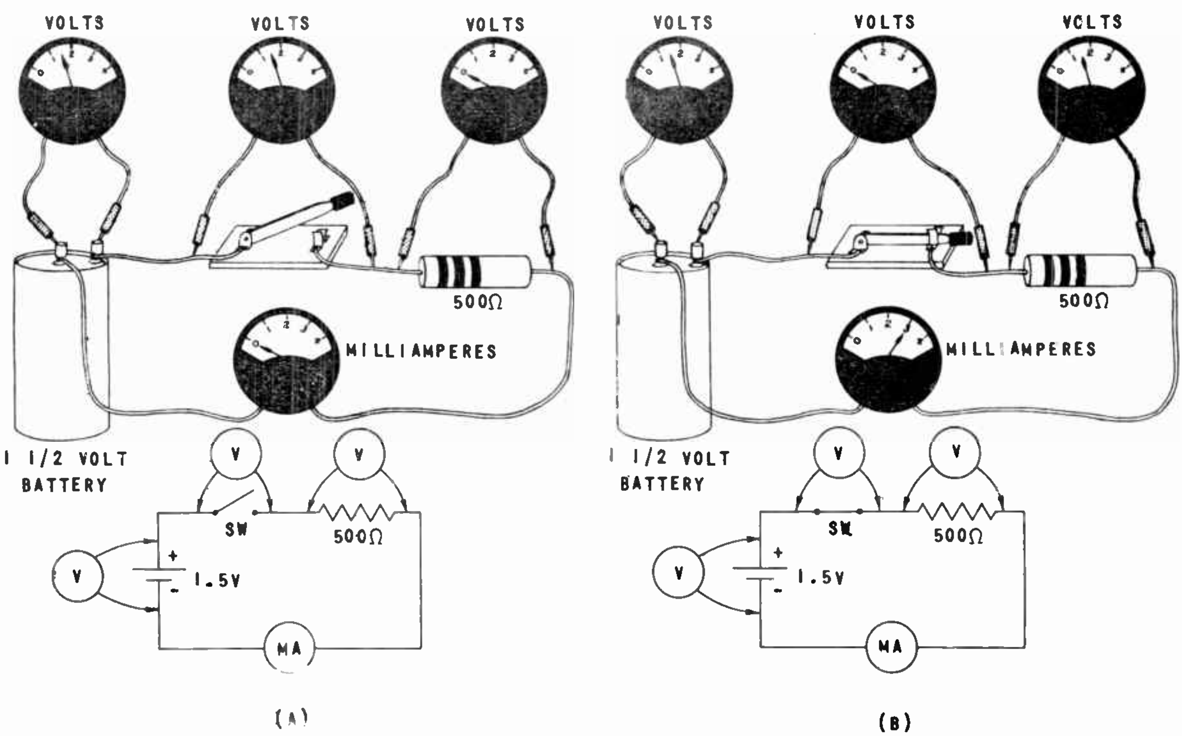


FIGURE 12

DEMONSTRATING THE USE OF OHM'S LAW IN SERIES CIRCUITS

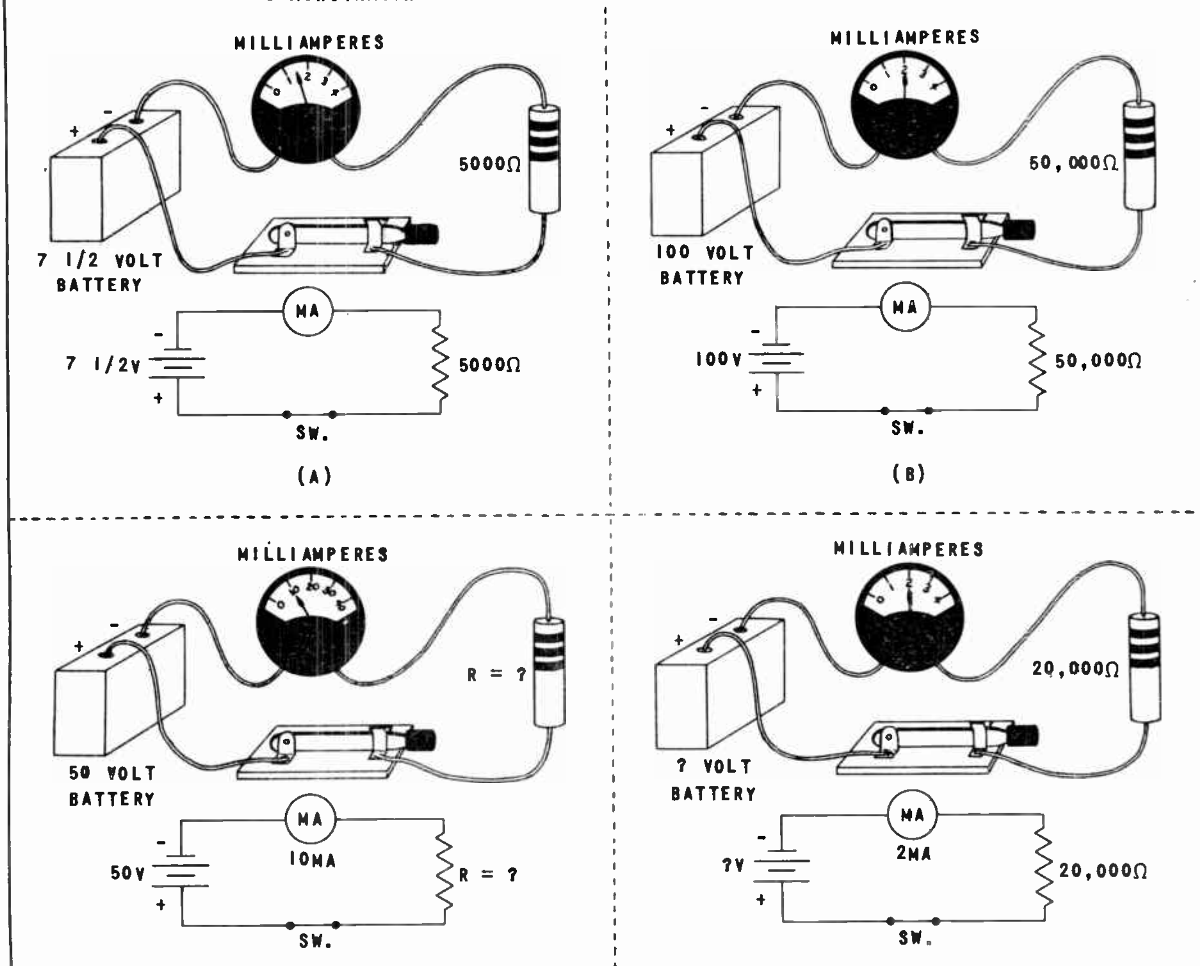


FIGURE 13

SERIES CIRCUIT CONTAINING TWO RESISTORS

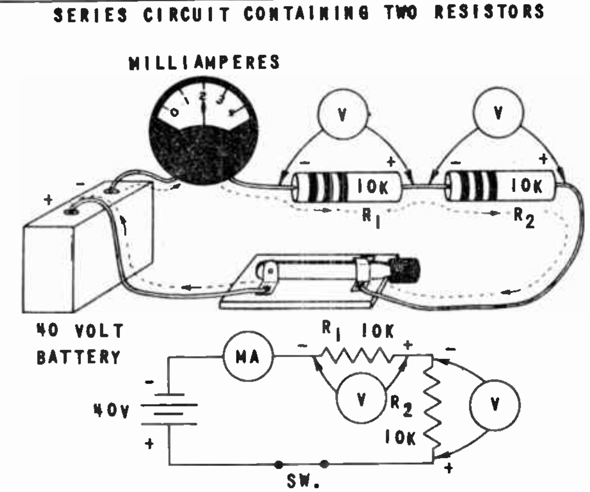


FIGURE 14

SERIES CIRCUIT CONTAINING SEVERAL RESISTANCES

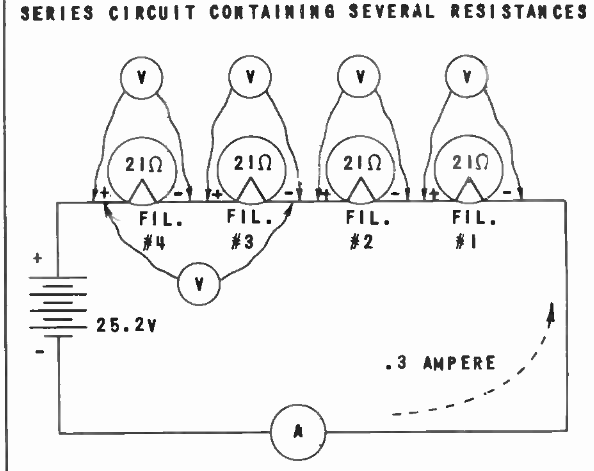


FIGURE 15

PARALLEL CIRCUIT

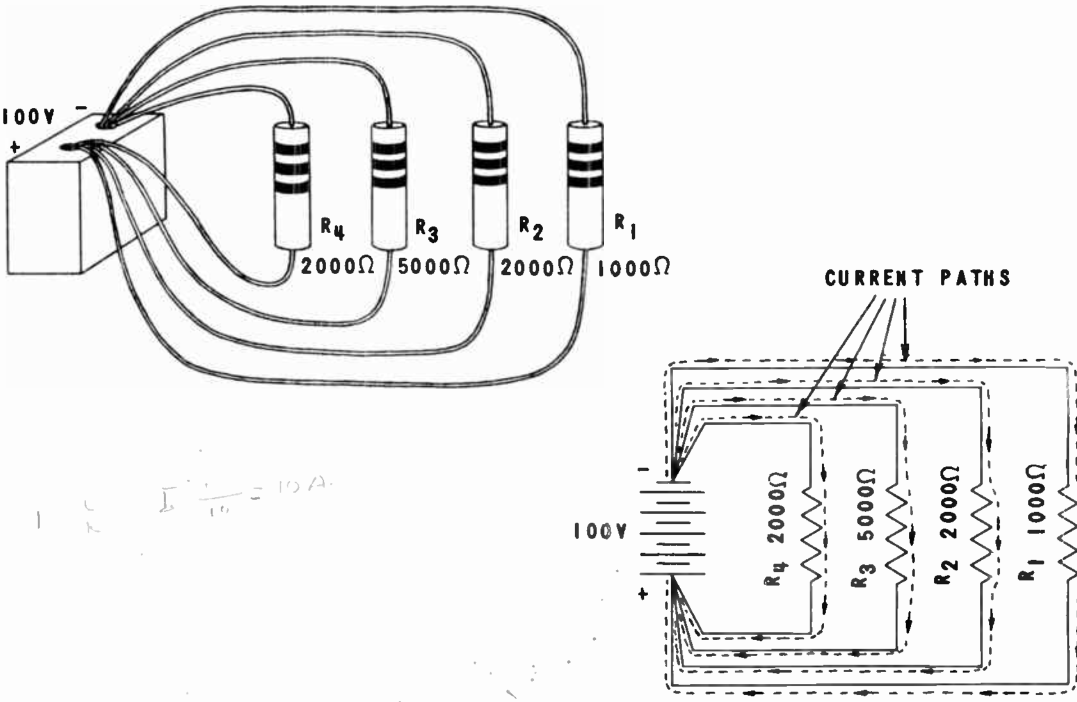


FIGURE 20

SERIES-PARALLEL CIRCUIT

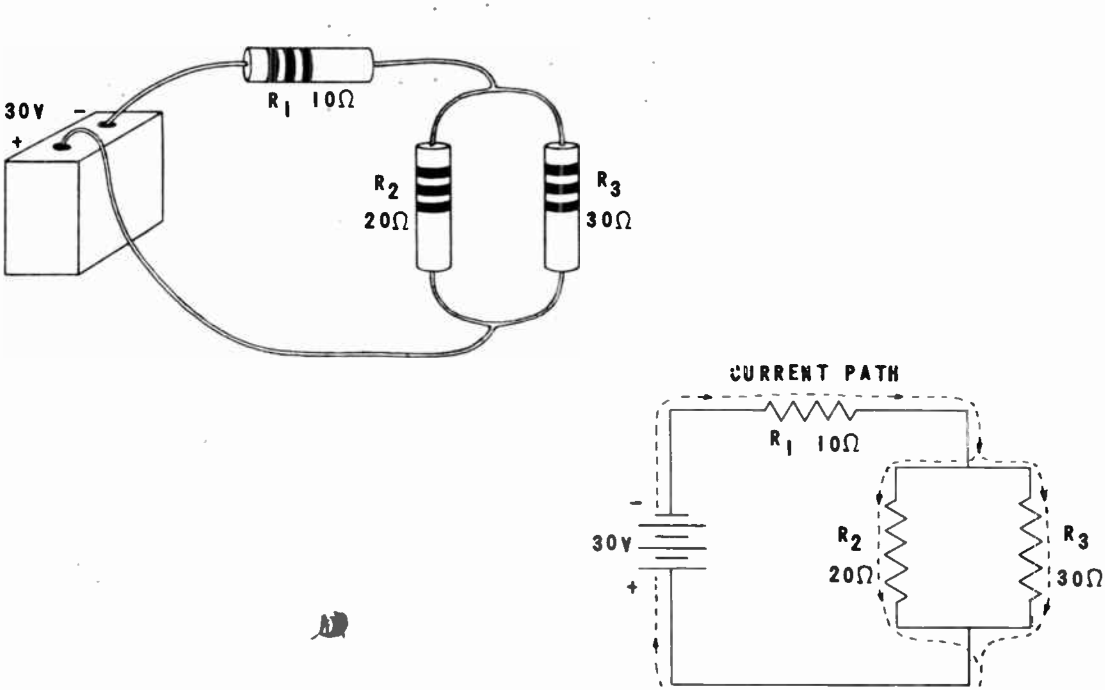


FIGURE 21

DEMONSTRATING THAT THE CURRENT IS THE SAME AT ANY POINT IN A SERIES CIRCUIT

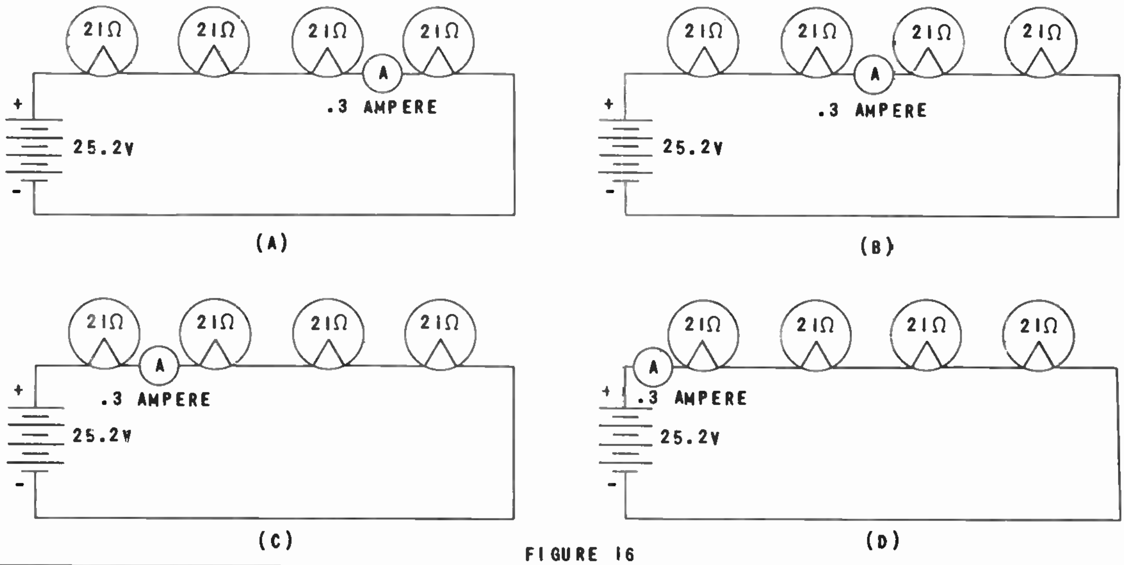


FIGURE 16

SERIES CIRCUIT

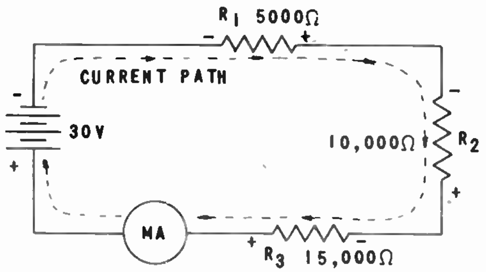


FIGURE 17

PARALLEL CIRCUIT

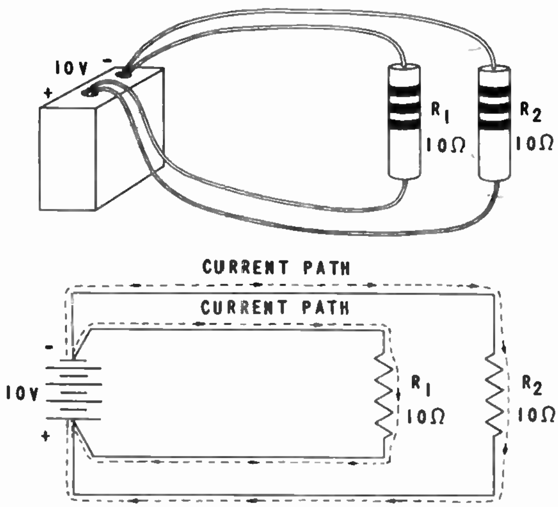
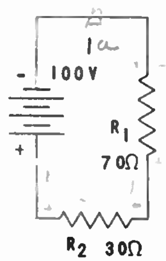


FIGURE 19

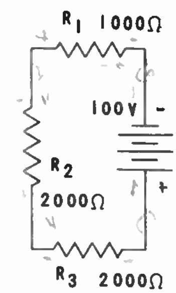
SERIES CIRCUIT PROBLEMS



FIND:
EQUIVALENT RESISTANCE OF R_1 AND R_2.
CURRENT WHICH WOULD FLOW IN CIRCUIT.
VOLTAGE DROP ACROSS R_1.
VOLTAGE DROP ACROSS R_2.

SHOW:
CURRENT PATH BY MEANS OF DOTTED LINE.
POLARITY OF EACH VOLTAGE DROP.

(A)



FIND:
EQUIVALENT RESISTANCE OF R_1, R_2 AND R_3.
CURRENT WHICH WOULD FLOW IN CIRCUIT.
VOLTAGE DROP ACROSS R_1.
VOLTAGE DROP ACROSS R_2.
VOLTAGE DROP ACROSS R_3.

SHOW:
CURRENT PATH BY MEANS OF DOTTED LINE.
POLARITY OF EACH VOLTAGE DROP.
FOUR WAYS IN WHICH A MILLIAMMETER COULD BE CONNECTED IN CIRCUIT.

(B)

FIGURE 18

VOLTAGE SOURCES

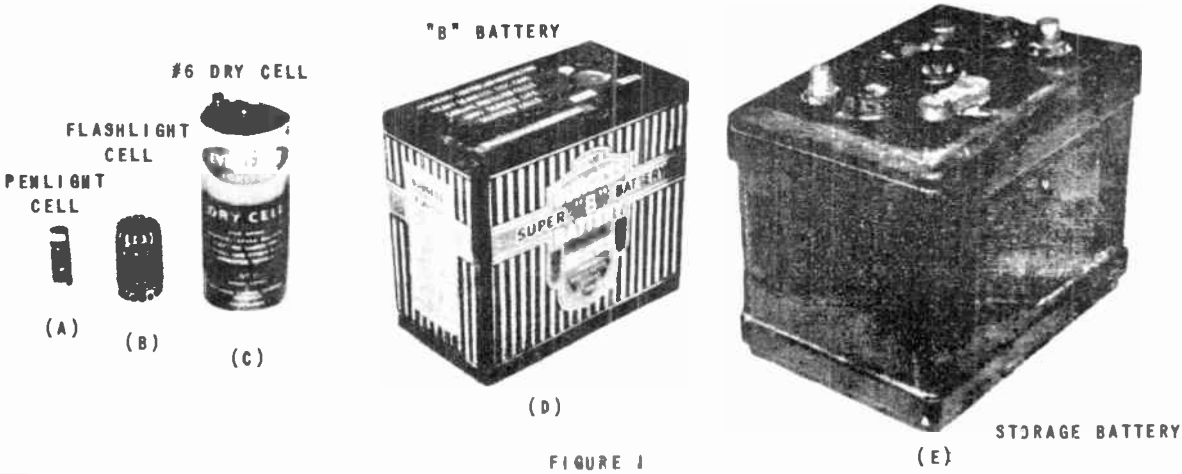


FIGURE 1

VOLTAGE SOURCES

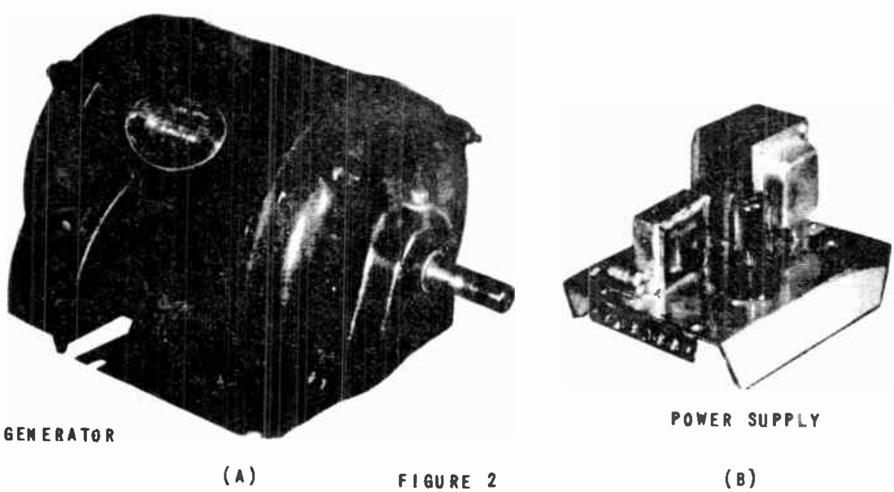


FIGURE 2

BATTERY SYMBOL

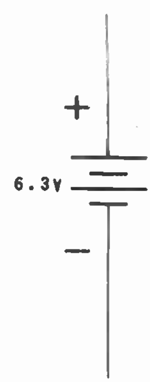


FIGURE 3

ILLUSTRATING TYPICAL VOLTMETERS AND METHOD OF MEASURING EMF OR VOLTAGE

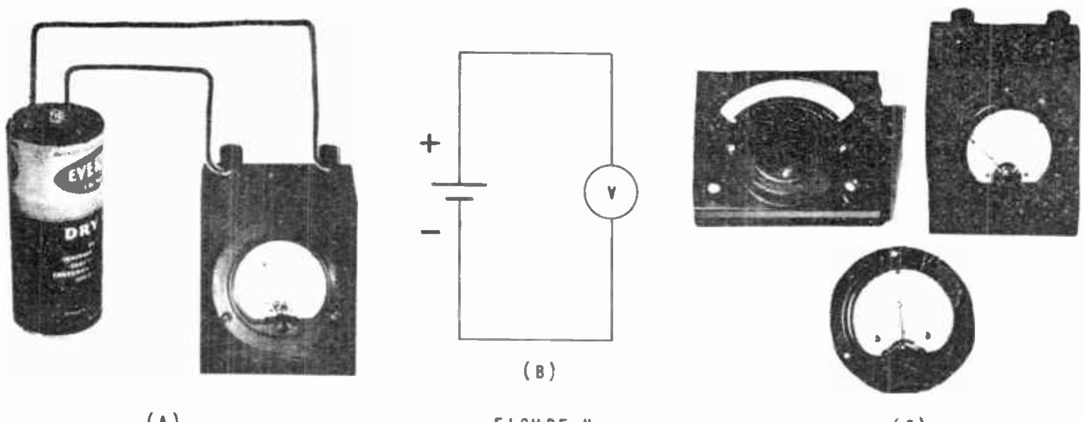


FIGURE 4

Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES
LOUISVILLE KENTUCKY

POWERS AND ROOTS: POWERS OF TEN

ASSIGNMENT 7

FOREWORD

When you glanced at the title of this assignment you may have said to yourself, "I want to be an electronics technician. Why are they teaching me math?" We think this is a very good question and deserves a logical answer. After all, if a person knows just WHY he is doing something, he'll do a better job. You are eager to become a competent electronics technician, and if you can see where you will really *need* math, then it is only natural that you will apply yourself better to the task of learning it.

A limited amount of mathematics has been included in the training program because math is a very useful "tool" to an electronics technician. In other words, it will help him to do his job better, quicker, and easier.

There will be many times when you, as an electronics technician, will apply this tool - mathematics - to the problem of trouble shooting. This doesn't mean that you will necessarily stop your trouble-shooting operation, take out a pencil and paper and solve a problem. It *does* mean that you will apply the principles of mathematics to your trouble shooting. Remember, electronics deals in physical quantities. For example, *amounts of current*, *amounts of voltage*, *amounts of resistance*. Only through an understanding of basic math can you understand, in your own mind, the relationship between these physical quantities.

Let us emphasize one point. The math included in the training program - and only a very small amount is included - is for the purpose of *helping you* in your future work in the electronics field. A UEL technician is far more than a "screwdriver mechanic," The UEL technician knows what he is doing, because he understands the principles of electronics. To do this, he must also understand the principles of mathematics.

Remember, we are going to give you only the math you *need;* we're going to give it in such a way that you can learn it if you did not have it in school, or if you didn't "like it" when you were in school. All we ask is that you approach it with the proper attitude. If you will decide that since you need this math *you are going to learn it*, then *we can guarantee that you will*. In fact, we assure you that you are going to be pleasantly surprised at just how easy the subject of math is!

ASSIGNMENT 7

POWERS AND ROOTS; POWERS OF TEN

In Assignment 4, we studied the arithmetic which will be used in solving the problems encountered in electronics. In this assignment we will deal with a slightly different form of mathematics. This the the subject of Powers and Roots.

In some electronics formulas we might be instructed to *square a number* or to *cube a number;* or we might be required to find the "square root" of a number. In this assignment we will learn how to perform these operations.

At first glance it might appear that some of the information in this assignment is difficult, but this is definitely *not* the case. There isn't a thing which you will do in this assignment which is more involved than simple arithmetic. The purpose of this assignment is to show you *simple* ways to do problems that might otherwise be difficult. In other words, this assignment gives you *simple short cuts* to use in electronics problems. Just study through this assignment a step at a time and you will be surprised at just how simple it is. Here we go . . .

Powers

The phrase "squaring a number" comes from the fact that if we take a number and multiply it by itself we obtain the area of a square having that number as the length of each side. Thus, a square room that is 12 feet on each side has a floor area of 12 x 12 = 144 square feet.

The phrase "cubing a number" comes from the fact that if we have a cube, its volume will be equal to the length of one side multiplied by itself two times. Thus, a packing crate that is 4 feet on a side has a volume of 4 x 4 x 4 = 64 cubic feet.

We all know that 12 x 12 = 144.

We "squared" the 12 to get 144.

Another way of writing 12 x 12 = 144 would be $12^2 = 144$.

12^2 can be read either "12 squared", or "12 to the second power".

The 12 is the *base*.

The 2 is the *exponent*. It is written as a small number to the right of and slightly higher than the base.

The exponent merely tells us how many times we are to use the base in multiplication.

Thus, if we cube the number 4, we could write it as 4^3 (which means 4 x 4 x 4) = 64.

Examples:

2^2 means 2 x 2 = 4.

4^5 means 4 x 4 x 4 x 4 x 4 = 1024 (4^5 is read as "4 to the fifth power").

6^3 means 6 x 6 x 6 = 216 (6^3 may be read as "6 cubed", or "6 to the third power").

10^2 means 10 x 10 = 100 (10^2 may be read as "10 squared" or "10 to the second power").

Numbers to be raised to a power may be written in parentheses, as $(4)^2$ or $(25)^3$; $(4)^2$ means the same thing as 4^2, and $(25)^3$ means the same as 25^3.

If the exponent is 1, we take the base one time. In other words, $4^1 = 4$, $10^1 = 10$, $3^1 = 3$, etc. Any number then has an exponent of 1 if no other exponent is indicated. Thus $4 = 4^1$, $10 = 10^1$, $3 = 3^1$, etc.

For practice, solve the following problems:

1. $5^2 =$	3. $25^2 =$	5. $9^4 =$	7. $7^7 =$
2. $7^1 =$	4. $73^3 =$	6. $10^3 =$	8. $2^9 =$

1- $14^2 =$

$$\begin{array}{r} 14 \\ \times 14 \\ \hline 56 \\ 14 \\ \hline 196 \end{array}$$

2- $\sqrt{121}$ = 11

$$\begin{array}{r|l} & 1 \\ \hline 21 & 21 \\ & 21 \\ \hline \end{array}$$

3- $4^5 = 4 \times 4 = 16 \times 4 = 64 \times 4 = 256$

$256 \times 4 = 1024$

4- $\sqrt{72}$ = 8.4853 — use [illegible]

5.

(a) $3000 = 3 \times 10^3$

(b) $.000009 = 9 \times 10^{-6}$

(c) $1 = 10^0$

(d) $9{,}000{,}000 = 9 \times 10^6$

Roots

The opposite of raising a number to a power is called finding the root of a number.

Thus: 3 cubed = 3 x 3 x 3 = 27. $4^2 = 16$.

The cube root of 27 is 3. The square root of 16 is 4.

We used exponents to indicate the power to which a number is to be raised. We use a radical sign ($\sqrt{\ }$) to indicate roots.

The cube root of 27 is written $\sqrt[3]{27}$.

The square root of 16 is written $\sqrt{16}$.

Notice that for square roots it is not necessary to indicate which root is being taken. In other words, if no particular root is shown, it is understood that we mean square root.

Thus: $\sqrt{81} = 9$ because we know that 9 x 9 = 81.

$\sqrt{64} = 8$ because we know that 8 x 8 = 64.

$\sqrt{144} = 12$ because we know that 12 x 12 = 144.

$\sqrt[3]{27} = 3$ because 3 x 3 x 3 = 27. ($\sqrt[3]{27}$ is read as the cube root of 27)

$\sqrt[4]{16} = 2$ because 2 x 2 x 2 x 2 = 16.

($\sqrt[4]{16}$ is read as the fourth root of 16)

In electronics problems you will find *very few* cases where the cube root of a number or any higher root than the second will be required, but you will find many problems in electronics work where the square root of a number will have to be determined. When you have $\sqrt{81}$, you ask yourself, "What number multiplied by itself gives 81?" The answer 9, is obvious. There are a great many cases where the roots are not obvious.

Since $\sqrt{81} = 9$, and $\sqrt{64} = 8$; $\sqrt{70}$ must be some odd decimal quantity between 8 and 9. Numbers, like 81, whose square root is a whole number, are called perfect squares. Thus, 64 is a perfect square since its square root is the whole number 8. Seventy is not a perfect square since its square root is not a whole number. Such a number is called an imperfect square.

There are three common methods of obtaining the square root of a number. One of these is by using a slide rule. You may be familiar with the operation of a slide rule; if not, do not feel concerned since the operation of a slide rule will not be required in this training program. The slide rule would tell you that the square root of 70 is approximately 8.37. Another method is to use mathematical tables. A mathematical table would tell you that the square root of 70 (to 5 significant figures) is 8.3666. You can also determine the square root of 70 (or any other number) by a "long-hand" method. A knowledge of this "long-hand" method is necessary before you can make intelligent use of the slide rule or a mathematical table. We will work out several square roots. Use these solutions as a guide when you start to work the problems at the end of the assignment. Let us first take the square root of 70. You will find that the same set of rules will apply no matter what number we work with.

EXAMPLE 1 $\sqrt{70}$ = ? or what number times itself equals 70?

$\overset{.}{\sqrt{70.}}$ *First step.* Locate the decimal point in the 70 and place a decimal point directly above the decimal point in the 70. We have now located the decimal point in our answer.

```
 ___________
√70.00 00 00
```

Second step. Use brackets to "pair off" the digits, or numbers. Start at the decimal and move to the left, placing the 0 and 7 under *one bracket*. Add zeros to the right of the decimal point. Start at the decimal point and move to the right, placing one bracket over each *pair* of digits. Notice that we *never* have a bracket crossing over the decimal point.

```
  8.
 ___________
√70.00 00 00
 64
```

Third step. Look under the first bracket. We find the quantity 70. The largest perfect square that will fit in 70 is 8 x 8 or 64. The next largest perfect square, 9 x 9 or 81, is larger than 70. Place the 64 under the 70 and the 8 as the first digit in the answer.

```
  8.
 ___________
√70.00 00 00
 64  | |
  6  00
```

Fourth step. Subtract the 64 from the 70 and bring down *both digits* under the next bracket.

```
        8.
       ___________
      √70.00 00 00
       64
16    |6 0 0

Trial Divisor
```

Fifth step. Obtain a trial divisor for the 600. To do this double the 8 in the answer. Place the trial divisor (2 x 8) = 16 to the left of the 600. We are going to place another figure after the 16 in a moment. We had better save a place for it. Mentally or actually cover up the last zero in the 600. This gives us 60. 16 goes into 60 three times (3 x 16 equals 48; 4 x 16 equals 64).

```
        8.3
       ___________
      √70.00 00 00
       64
163   |6 00
```

Sixth step. Place the 3 after the 16 and also enter 3 as the next digit in the answer. Notice that each bracket (pair of digits) gives us a place for one digit in our answer.

```
        8.3
       ___________
      √70.00 00 00
       64
163   |6 00  |
      |4 89  |
       1 11 00
```

Seventh step. Enter 3 times 163 or 489 under the 600 and subtract it, leaving 111. Bring down the *next pair* of digits.

```
        8.3
       ___________
      √70.00 00 00
       64
163   |6 00
      |4 89
166   |1 11 00

Trial Divisor
```

Eighth step. Obtain a trial divisor for the 11100. Simply double the 83 in the answer (2 x 83 = 166). Covering the last zero in 11100 we see that 166 goes into 1110 six times (6 x 166 = 996; 7 x 166 = 1162).

```
      8.3   6
   √ 70.00 00 00
     64
163   6 00
      4 89
1666  1 11 00
        99 96
        11 04 00
```

Ninth step. Enter the 6 after the 166 and also in the answer. Enter 6 times 1666 or 9996 under the 11100 and subtract. Bring down the next pair of digits.

```
       8.3   6  6
    √ 70.00 00 00
      64
163    6 00
       4 89
1666   1 11 00
         99 96
16726    11 04 00
         10 03 56
          1 00 44
```

Tenth step. Our next trial divisor is 2 x 836 = 1672. Our trial divisor goes into 11040 six times. Enter the 6 after the 1672 and also as the next digit in our answer. Multiply the 16726 by 6 and subtract it from the 110400.

If we wanted to carry our answer out to more significant figures, we could add more pairs of zeros which could give us more brackets and more places in our answer. *Each* additional *bracket* would give us *one* more *place in our answer.*

If we are satisfied with four significant figures, our work is complete. Notice that we have a remainder of 10044. Tracing the path of the decimal in our 70 straight down, we see that our remainder is really .010044.

Let us check our answer.

```
   8.366          Adding our remainder:
   8.366
   50196              69.989956
  50196                 .010044
 25098                70.000000
66928
69.989956
```

EXAMPLE 2. What is the square root of .0000044 to four significant figures?

$$\sqrt{.00\ 00\ 04\ 40\ 00\ 00}$$

Locate the decimal point in the answer. Mark off pairs of digits with brackets, adding enough zeros to provide brackets for four significant figures.

```
  . 0  0
√ .00 00 04 40 00 00
```

All we find under the first two brackets are zeros. The first two digits in our answer will be zeros.

```
  . 0  0  2
√ .00 00 04 40 00 00
          4
          40
```

Under the next bracket we find a 4. The largest square in 4 is $(2)^2$. Enter the 2 and 4 as shown. Subtract the 4 from 4 and bring down the pair of digits under the next bracket.

```
  . 0  0  2
√ .00 00 04 40 00 00
          4
      4 | 40
```

Our trial divisor is double the 2 in our answer or 4. Covering up the zero in 40 we have 4. We have 4 divided into 4 which goes once. Entering the 1 in our

```
  . 0  0  2  1
 √. 00 00 04 40 00 00
           4 ↓↓
 41         |40
            |41
```

answer and after the 4 we place 1 x 41 or 41 under the 40 for subtraction. 41 is too large to be subtracted from 40. Therefore 1 is too large a number for the next digit in our answer. The next smaller number is zero.

```
  . 0  0  2  0 . 9
 √. 00 00 04 40 00 00
           4     ↓↓
 409        |40 00
```

In place of the 1's enter zeros in the answer and after the 4. *Bring down the next two digits.* Our trial divisor of 40 goes into 400 ten times. 9 is the largest digit we can use so place 9 as the next digit in the answer and in the divisor.

```
  . 0  0  2  0  9
 √. 00 00 04 40 00 00
           4
 409        |40 00
            |36 81  ↓↓
               3 19 00
```

Subtract 9 x 409 from the 4000 and bring down the next pair of digits.

```
  . 0  0  2  0  9  7
 √. 00 00 04 40 00 00
           4
 409        |40 00
            |36 81
 4187        |3 19 00
             |2 93 09
                 25 91
```

Our next trial divisor is twice 209 or 418. Our trial divisor 418 goes into 3190 seven times. Enter the 7 in the answer and after the 418. Subtract 4187 times 7 from 31900.

```
Check.         .002097          Adding the remainder:
               .002097
                 14679          .000004397409
                18873           .000000002591
                4194            .000004400000
            .000004397409
```

Follow the work carefully in these next square root problems. You will soon realize that there are really very few rules to remember. Using these problems as a guide, you should be able to work out the five square root problems that are given. You will have to use square roots again in some of the "Powers of Ten" problems at the end of this assignment.

EXAMPLE 3. Find the square root of 732.8 to 4 significant figures.

```
        2  7. 0  7
      √ 7 32.80 00
        4
 4 7   |3 32
       |3 29
 5407    |3 80 00
         |3 78 49
             1 51
```

In marking brackets to the left of the decimal you will have *one* figure by itself under a bracket if there are an odd number of digits to the left of the decimal. In this case the largest perfect square in 7 is 2 x 2 or 4. Putting the two in the first place in our answer, we proceed as in the other examples. In our first trial divisor step, 4 divided into 33 goes eight times. Since 8 x 48 = 384 (more than 332), we have to use 7. Our second trial divisor (54) was too large for 38 so the third digit in our answer is zero. When the next *pair* of digits is brought down, we find that our new trial divisor, 540, goes into 3800, 7 times. This gives 7 for the fourth figure in our answer.

```
Check.        27.07
              27.07
              -----
              18949
             18949
             5414
             -------
             732.7849  =  732.7849
                          + .0151
                          --------
                          732.8000
```

EXAMPLE 4. Find the square root of 827,564,581 to 4 significant figures.

```
          2  8  7  6  0.
        √8 27 56 45 81.
         4
 48     |4 27
        |3 84
 567      |43 56
          |39 69
 5746       |3 87 45
            |3 44 76
               42 69 81
```

We put a zero in our answer for our last digit since we were asked for only 4 significant figures.

Check this answer.

EXAMPLE 5. Find the square root of 58.9 to 3 significant figures.

```
          7.  6  7
        √58. 90 00
          49
  146    |9 90
         |8 76
  1527   |1 14 00
         |1 06 89
              7 11
```

Check this answer.

EXAMPLE 6. Find the square root of .021 to 3 significant figures.

```
          .  1  4  4
        √.02 10 00
              1
  24        |1 10
            |  96
  284          |14 00
               |11 36
                 2 64
```

Check this answer.

For practice, solve the following problems. Find the square roots to 4 significant figures.

$\sqrt{.0021}$ $\sqrt{.00021}$ $\sqrt{59730}$ $\sqrt{2}$ $\sqrt{3.75}$

Powers of Ten

In electronics and television work we will quite often encounter very large numbers and very small decimal fractions. For example, we will have numbers like 40 megacycles, which means 40,000,000 cycles; 1000 kilocycles, which means

1,000,000 cycles; and 10 micromicrofarads, which means .000000000010 farads. Handling these large numbers in solving problems is very inconvenient, and leads to a large number of errors. Example 1 gives a sample of this type of problem.

Example 1. This problem can be completed, and the correct answer obtained as long as we are careful in using the decimal point. Since the decimal quantities are so long, a considerable amount of careful work is necessary if the decimal point is to be properly placed in the answer.

$$F = \frac{.159}{\sqrt{.00015 \times .000000000004}}$$

$$F = \frac{.159}{\sqrt{.000\ 000\ 000\ 000\ 000\ 6}}$$

You will be dealing with these very large and very small quantities throughout your entire electronics and television work, so you should welcome any method that conveniently takes care of these quantities.

The *Powers of Ten* will do just that. Powers of ten are often referred to as *Engineer's Shorthand.*

In the section on Powers and Roots you found that in the expression 3^4 we had a *base* (3) and *exponent* (^{4}). The expression means 3 x 3 x 3 x 3 = 81.

Similarly:

4^3 means 4 x 4 x 4 or 64
2^5 means 2 x 2 x 2 x 2 x 2 or 32
7^2 means 7 x 7 or 49
10^2 means 10 x 10 or 100
10^4 means 10 x 10 x 10 x 10 or 10,000

We can see then that number 10 is easier to work with as a base than 3, 4, 2, 7, or most any other number.

Also, the number 10 ties in perfectly with our decimal system. Thus: The number 20 is *ten* times as large as the number 2, the only difference between the two numbers is the position of the decimal point with respect to the 2.

Let us make up a table of powers of ten. This table will be used as a reference in explaining how powers of ten work. Examine this table carefully to learn just how it is made up. It will not be necessary for you to memorize the values given in the table.

10^6	means 10 x 10 x 10 x 10 x 10 x 10	=	1,000,000
10^5	means 10 x 10 x 10 x 10 x 10	=	100,000
10^4	means 10 x 10 x 10 x 10	=	10,000
10^3	means 10 x 10 x 10	=	1,000
10^2	means 10 x 10	=	100
10^1	means 10	=	10
10^0	means 10 ÷ 10	=	1
10^{-1}	means $\frac{1}{10}$	=	.1
10^{-2}	means $\frac{1}{10 \times 10}$	=	.01
10^{-3}	means $\frac{1}{10 \times 10 \times 10}$	=	.001
10^{-4}	means $\frac{1}{10 \times 10 \times 10 \times 10}$	=	.0001

10^{-5} means $\frac{1}{10 \times 10 \times 10 \times 10 \times 10}$ = .00001

10^{-6} means $\frac{1}{10 \times 10 \times 10 \times 10 \times 10 \times 10}$ = .000001

From 10^6 on down to 10^2 you could have made up the table yourself. From 10^1 on down we can make a few general statements. Then we can begin to see how the whole thing works out.

If you have the number 10 in a problem, it actually has an exponent of 1. You should remember then that $10 = 10^1$ whether the exponent is actually shown or not.

10^0 is *definitely* equal to 1. This is usually the hardest thing for students to see in the entire table. Just remember that 10^0 means $\frac{10}{10}$ which is, of course, equal to 1. Any base with an exponent of 0 is equal to 1. Thus 2^0 equals 1, since it means $\frac{2}{2}$. Also, $465^0 = 1$, $10^0 = 1$.

The 10's with negative exponents (-1, -2, etc.) indicate that 10 is to be taken a certain number of times in the *denominator* of a fraction whose numerator is 1. Thus, 10^{-1} means $\frac{1}{10}$; $10^{-2} = \frac{1}{10 \times 10} = \frac{1}{100}$; and $10^{-3} = \frac{1}{10 \times 10 \times 10} = \frac{1}{1000}$. Notice that 10^3 means 1000 and 10^{-3} means $\frac{1}{1000}$. Also 10^6 equals 1,000,000 and 10^{-6} equals $\frac{1}{1,000,000}$.

Multiplication With Powers of Ten

We will work out a few simple multiplication problems by arithmetic, and see what the results would be in powers of ten.

Example 1. 100 x 1000 = 100,000

Let us glance at the Powers of Ten Table, and change each of the figures in the problem to powers of 10.

100 x 1000 = 100,000
$10^2 \times 10^3 = 10^5$

Example 2. 10 x 100 = 1000
In powers of ten, $10^1 \times 10^2 = 10^3$

Example 3. 100 x .001 = .1
In powers of ten, $10^2 \times 10^{-3} = 10^{-1}$

Example 4. .01 x .001 = .00001
In powers of ten, $10^{-2} \times 10^{-3} = 10^{-5}$

Now let us examine Example 1 closely. We worked this problem out by the long method of multiplication and are sure that the answer (100,000) is correct. Now look at the powers of ten used to represent each number in the example. The number 10^2 is equal to 100; 10^3 is equal to 1000; and 10^5 is equal to 100,000. Notice that in multiplying the two numbers together, 10^2 and 10^3, we did not multiply the exponents together, but we *added the exponents*. We might write it in this manner: $10^2 \times 10^3 = 10^{2+3} = 10^5$.

This illustrates one rule for using powers of 10. *When multiplying with powers of 10, add the exponents.*

Let us check this rule in Examples 2, 3 and 4.

Example 2 could be rewritten $10^1 \times 10^2 = 10^{1+2} = 10^3$. The step of writing 10^{1+2} is unnecessary in actual work and is merely shown here for clarity.

In Example 3 we have $10^2 \times 10^{-3}$. To solve this by powers of 10 we have $10^{2-3} = 10^{-1}$. Here we add a +2 and a -3. If the addition of negative numbers confuses you, an easy thing to do is to think of the positive numbers as money you have and the negative numbers as money you owe. In this case, if you had 2 dollars and owed 3, when you pay the two dollars on your debt, you still owe one dollar. $2 - 3 = -1$.

In Example 4 we have $10^{-2} \times 10^{-3}$. This would be $10^{-2-3} = 10^{-5}$. Here we are adding two negative numbers, -2 and -3. If you owed one person two dollars and another person 3 dollars, you would owe a total of 5 dollars.

Let us solve a few multiplication problems with powers of 10.

Example 5. $100 \times 10{,}000 = ?$

$10^2 \times 10^4$

When we look up 100 and 10,000 in our table, we may rewrite the problem: $10^2 \times 10^4$.

$10^2 \times 10^4 = 10^{2+4} = 10^6 = 1{,}000{,}000$

Adding our exponents, we obtain the answer.

Work this problem by the long method of multiplication, and check to see if the answer is the same as that obtained with powers of 10.

Example 6. $1{,}000{,}000 \times \frac{1}{1{,}000} = ?$

Changing to powers of 10, $10^6 \times 10^{-3} = 10^{6-3} = 10^3 = 1{,}000$

Check this by the long method.

Example 7. $\frac{1}{10{,}000} \times \frac{1}{1{,}000}$

$10^{-4} \times 10^{-3} = 10^{-7}$.

The answer, 10^{-7}, means $\frac{1}{10{,}000{,}000}$. This was not shown on our original table. This is because our table is not complete. The powers of 10 do not start at 6 and end at -6. Actually they can be continued on to any value. A very simple way to remember this is: To change a power of 10 to a number, write 1 and add as many zeros after the 1 as the exponent of the power of ten. Then, 10^1 would be 1 followed by one zero or 10. 10^6 would be 1 followed by 6 zeros, or 1,000,000. 10^{12} would be 1 followed by twelve zeros, or 1,000,000,000,000. 10^{-7} would be $\frac{1}{\text{1 followed by seven zeros}}$ $\frac{1}{10{,}000{,}000}$.

It is just as simple to change numbers into powers of 10. Just use for the exponent of 10 the number of zeros after the one in the number. Thus, to change 10,000, which is 1 followed by four zeros, to powers of 10, we write 10^4. 100 is 10^2 and 1000 is 10^3 $\frac{1}{100}$ is 10^{-2} and $\frac{1}{10{,}000{,}000} = 10^{-7}$.

For practice, solve the following problems using powers of ten. If in doubt, check your answer using the long method.

1. $10^4 \times 10^6$
2. $1000 \times 1{,}000{,}000$
3. $10^3 \times 10^{-2}$
4. $10{,}000 \times \frac{1}{1{,}000}$
5. $100 \times \frac{1}{100}$

Division With Powers of Ten

Let us find how to use powers of ten in division.

Example. Suppose we wish to divide 1000 by 100. $\frac{1000}{100} = 10.$

We find by mathematics that the answer is 10 or 10^1.

Let us write this in powers of ten.

$$\frac{10^3}{10^2} = 10^1$$

We can obtain the 10^1 by changing the sign of the exponent of the denominator (bottom number in the fraction) and then adding exponents.

In this example,

$$\frac{10^3}{10^2} = 10^{3-2} = 10^1$$

We changed the exponent 2 to a -2 since it is in the denominator.

Let us apply this method to a few more examples.

Example 2. Divide 10,000 by 10.

$$\frac{10^4}{10^1} = 10^{4-1} = 10^3. \quad 10^3 \text{ is equal to } 1000.$$

Example 3. Divide 100 by .00001.

$$\frac{10^2}{10^{-5}} = 10^{2+5} = 10^7.$$ Check this problem by the long method.

Example 4. $\frac{10^{-2}}{10^{-3}} = 10^{-2+3} = 10^1 = 10.$

For practice, solve the following problems with powers of ten.

1. $\frac{10^6}{10^{-5}}$ 2. $\frac{10^{-2}}{10^{-4}}$ 3. $\frac{10^3}{10^6}$ 4. $\frac{10^{-4}}{10^{-12}}$

It is permissible to change a power of ten from the top to the bottom, or from the bottom to the top of a fraction merely by changing the sign of the exponent. We have actually been doing this in the division problems just solved.

Example 1. $\frac{10^3}{10^2} = \frac{10^{3-2}}{1} = \frac{10^1}{1} = 10.$

This could have been written $\frac{10^3 \times 10^{-2}}{1} = 10^1.$

In this case we moved the 10^2 from the denominator to the numerator of the fraction, and changed the sign of the exponent so that our power of ten is now 10^{-2}. Then we multiplied by powers of ten to obtain our answer.

This problem could be solved in the following manner:

$$\frac{10^3}{10^2} = \frac{1}{10^2 \times 10^{-3}} = \frac{1}{10^{-1}} = \frac{1}{.1} = 10.$$

In this case we moved the 10^3 from the numerator to the denominator, and changed the exponent's sign so that we had 10^{-3}. Then we multiplied, using powers of 10.

This may seem to be a rather useless operation with the simple problem in Example 1, but will be very handy in the solution of more complex problems.

Let us apply this principle to a few more problems.

Example 2. $\frac{10^2}{10^6} = \frac{10^2 \times 10^{-6}}{1} = 10^{-4}$

Example 3. $\frac{10^2}{10^6} = \frac{1}{10^6 \times 10^{-2}} = \frac{1}{10^4} = \frac{10^{-4}}{1}$

Example 4. $\frac{10^3 \times 104}{10^6 \times 10^{-5}} = \frac{10^7}{10^1} = \frac{10^7 \times 10^{-1}}{1} = 10^6$

Changing Numbers into Powers of 10

Any number, large or small, can be broken up into a workable figure times a power of ten.

Thus: $200 = 2 \times 100 = 2 \times 10^2$

$270000 = 27 \times 10000 = 27 \times 10^4$

or $270000 = 2.7 \times 100000 = 2.7 \times 10^5$

$3600000000 = 36 \times 10^8 = 3.6 \times 10^9$

$.2 = 2 \times .1 = 2 \times 10^{-1}$

$.003 = 3 \times .001 = 3 \times 10^{-3}$

$.00000085 = 8.5 \times .0000001 = 8.5 \times 10^{-7}$

or $.00000085 = 85 \times .00000001 = 85 \times 10^{-8}$

Check the above figures until you are satisfied that they are correct. Notice that in each case the number of the exponent tells us the number of places we have moved our decimal point. The + or - sign in front of the exponent tells us whether we have moved our decimal to the left or right.

(a) 27 00 00. = 27×10^4 (c) .00 00 00 85 = 8.5×10^{-7}

(b) .00 00 00 27 = 27×10^{-8} (d) 63 00 00 00 = 6.3×10^7

Moving the decimal to the left gives us a positive exponent. Moving the decimal to the right gives us a negative exponent.

For practice, express the following as whole numbers times a power of 10.

1.	36000	3.	930000	5.	.00000081
2.	.0004	4.	72100	6.	.000000000043

Except for a few helpful hints we have covered the subject of powers of ten. The four simple rules (which you should be careful to understand rather than memorize) are:

1. In multiplication of powers of ten, *add exponents.*
2. A power of ten can be moved from denominator to numerator of a fraction (and vice versa) providing the *sign of the exponent is changed.*
3. The numerical value of the exponent tells us how many places we have moved the decimal point.
4. The sign of the exponent tells us in what direction we have moved the decimal point.

Now let us use the powers of 10 to solve some more complex problems.

Example 1. $\frac{.000014 \times .00016}{.00000056 \times 2000} = \frac{14 \times 10^{-6} \times 16 \times 10^{-5}}{56 \times 10^{-8} \times 2 \times 10^3}$

The next thing to do is to combine the powers of 10 in the numerator and denominator. Remember 2 x 6 x 8 is the same as 8 x 6 x 2, or 6 x 2 x 8. In multiplication, it makes no difference in what order we proceed, so it is permissible for us to re-write the fraction as follows:

$$\frac{14 \times 16 \times 10^{-6} \times 10^{-5}}{56 \times 2 \times 10^{-8} \times 10^{3}}$$

$$\frac{14 \times 16 \times 10^{-11}}{56 \times 2 \times 10^{-5}}$$

Now we combine the powers of 10 in the numerator and denominator. (After some practice you will be able to do this mentally and will not have to write this step).

Now we cancel.

$$\frac{\overset{2}{\cancel{14}} \times \overset{1}{\cancel{\overset{2}{\cancel{16}}}} \times 10^{-11}}{\underset{1}{\cancel{\underset{8}{\cancel{56}}}} \times \cancel{2} \times 10^{-5}} = \frac{2 \times 10^{-11}}{10^{-5}} = \frac{2 \times 10^{-11} \times 10^{+5}}{1} = 2 \times 10^{-6} = .000002.$$

Apply the long method to obtain the answer to this problem to check the answer. Do you now see how the powers of 10 will save time and effort?

Example 2. $\dfrac{6000}{.00009 \times .01 \times 400 \times .00001} = \dfrac{6 \times 10^{3}}{9 \times 10^{-5} \times 10^{-2} \times 4 \times 10^{2} \times 10^{-5}} =$

$$\frac{6 \times 10^{3}}{9 \times 4 \times 10^{-5} \times 10^{-2} \times 10^{-5} \times 10^{2}} =$$

$$\frac{\overset{1}{\cancel{\overset{2}{\cancel{6}}}} \times 10^{3}}{\underset{3}{\cancel{9}} \times \underset{2}{\cancel{4}} \times 10^{-10}} = \frac{10^{3}}{6 \times 10^{-10}} = \frac{10^{3} \times 10^{10}}{6} = \frac{10^{13}}{6}$$

We have our answer $\frac{10^{13}}{6}$; but we may convert it in the form of a decimal. We could of course divide 6 into 10,000,000,000,000 but this would be using big numbers again. The simplest method is to change 10^{13} to $\frac{10^{1} \times 10^{12}}{6}$. Then rewrite the fraction.

$\frac{10^{1} \times 10^{12}}{6}$ Now all we have to do is to divide 6 into 10 (10^{1} is 10). We do this by division and find that 6 goes into 10, 1.67 times. Our answer can be re-written to be:

1.67×10^{12} It is a good idea to leave the answer in this form, since we are familiar enough with powers of 10 to know just what 10^{12} means. If we wanted to write our answer for someone not familiar with powers of 10 it would be 1,670,000,000,000.

Example 3. $\dfrac{.000012 \times .01 \times .003}{2400 \times 40000} = \dfrac{12 \times 10^{-6} \times 10^{-2} \times 3 \times 10^{-3}}{24 \times 10^{2} \times 4 \times 10^{4}}$

$$\frac{\overset{1}{\cancel{12}} \times 3 \times 10^{-11}}{\underset{2}{\cancel{24}} \times 4 \times 10^{6}} = \frac{3 \times 10^{-11}}{8 \times 10^{6}} = \frac{3 \times 10^{-11} \times 10^{-6}}{8} = \frac{3 \times 10^{-17}}{8} =$$

$$\frac{3 \times 10^{1} \times 10^{-18}}{8} = \frac{30 \times 10^{-18}}{8} = 3.75 \times 10^{-18}$$

Study this example carefully making sure you understand each step. Do you see why the 10^{-17} was changed to $10^{1} \times 10^{-18}$?

For practice, solve the following problems. Express your answers in a number between one and ten. times a power of ten.

1. $\frac{.0000008}{.002}$

2. $\frac{.00009}{6000}$

3. $\frac{45{,}000 \times 10^3}{.0005 \times .003}$

4. $\frac{625{,}000 \times 9800 \times 10^{-3} \times .0036}{350 \times 6.3 \times 10^4 \times .004 \times 10^6}$

Square Roots With Powers of Ten

Powers of 10 give a very convenient method of extracting square roots. Let us use some examples to demonstrate the process.

Example 1. $\sqrt{10{,}000} = 100$ since $100 \times 100 = 10{,}000$

Let us put this in powers of ten: $\sqrt{10^4} = 10^2$ since $10^2 \times 10^2 = 10^4$

Example 2. $\sqrt{.00000001} = .0001$ since $.0001 \times .0001 = .00000001$

Stated in powers of ten: $\sqrt{10^{-8}} = 10^{-4}$ since $10^{-4} \times 10^{-4} = 10^{-8}$

These examples illustrate that to take the square root of a power of 10 we merely divide the exponent by two. In example 1 the square root of 10^4 is 10^2 since the exponent 2 is one half of 4.

In example 2, the square root of 10^{-8} is 10^{-4} since the exponent -4 is one half of -8.

Example 3. $\sqrt{1{,}000{,}000} = \sqrt{10^6} = 10^3$

Example 4. $\sqrt{\frac{1}{100}} = \sqrt{10^{-2}} = 10^{-1}$

Now let us use this method for numbers consisting of whole numbers and powers of 10.

Example 5. $\sqrt{.0008 \times .00009} = \sqrt{8 \times 10^{-4} \times .9 \times 10^{-4}}$

$= \sqrt{7.2 \times 10^{-8}} = 2.68 \times 10^{-4}$ ($\sqrt{7.2}$ is 2.68)

Note: We were careful to move our decimal point so that the power of ten under the radical was an *even* number. You can see that if we had an odd exponent under the radical sign we would have ended up with a fractional exponent. (There is nothing wrong with a fractional exponent except that they are much harder to handle in a problem.)

Example 6. $\frac{1}{\sqrt{.0008 \times .00009}} = \frac{1}{\sqrt{8 \times 10^{-4} \times .9 \times 10^{-4}}}$

$= \frac{1}{\sqrt{7.2 \times 10^{-8}}} = \frac{1}{2.68 \times 10^{-4}} = \frac{10^4}{2.68} = \frac{10 \times 10^3}{2.68} = 3.73 \times 10^3$

Example 7. $\sqrt{7 \times 10^9}$

$\sqrt{7 \times 10^9} = \sqrt{70 \times 10^8} = 8.37 \times 10^4$ (Note: Square root of 70 = 8.37)

Example 8. $\sqrt{.07 \times .00008} = \sqrt{.7 \times 10^{-1} \times 8 \times 10^{-5}}$

$= \sqrt{5.6 \times 10^{-6}} = 2.37 \times 10^{-3}$ (2.37 is the square root of 5.6)

For practice, use the powers of ten to solve the following problems:

1. $\sqrt{.0009}$
2. $\sqrt{.00000004}$
3. $\sqrt{.009 \times .0008}$
4. $\sqrt{36 \times 10^3 \times 4 \times 10^7}$
5. $\sqrt{37 \times 10^6 \times .12 \times 10^8}$

In the above examples where we had several numbers *multiplied* together inside the radical sign, we could have taken the square roots of the different numbers individually and multiplied our answers together. The same thing holds true for division inside the radical sign. Let us solve Example 8 using this method.

Example 8. $\sqrt{.07 \times .00008} = \sqrt{7 \times 10^{-2}} \times \sqrt{.8 \times 10^{-4}}$

$2.65 \times 10^{-1} \times .894 \times 10^{-2} = 2.37 \times 10^{-3}$

If we have *addition* or *subtraction* inside the radical sign, the addition or subtraction *must* be performed before the square root is taken.

For example: $\sqrt{7 + 8} = \sqrt{15} = 3.87$

Addition and Subtraction with Powers of Ten

Powers of ten are particularly beneficial in the operations already explained. They are of little benefit when adding or subtracting.

In all addition or subtraction we are "tied down" when using powers of ten. Remember that in our work on decimals we were always careful to keep the decimal points in a vertical column. Since the exponent in our power of ten locates the decimal point, *the powers of ten of all numbers must be identical before they can be added or subtracted.*

Example 1. Add 7×10^{-5}, 86×10^{-4}, 33×10^{-6}

Answer:

$$\begin{array}{r} 70 \times 10^{-6} \\ 8600 \times 10^{-6} \\ 33 \times 10^{-6} \\ \hline 8703 \times 10^{-6} \end{array} \quad (\text{or } 8.703 \times 10^{-3})$$

Example 2. Add 3.7×10^{3}, 4.3×10^{6}, 37×10^{5}

Answer:

$$\begin{array}{r} 3.7 \times 10^{3} \\ 4300. \times 10^{3} \\ 3700. \times 10^{3} \\ \hline 8003.7 \times 10^{3} \end{array} \quad (\text{or } 8.0037 \times 10^{6})$$

You will see and use the words mega, kilo, milli, and micro throughout your radio and television work. Powers of ten provide an easy means of dealing with these terms.

Simply remember that:

Mega means million or 1,000,000 or 10^{6}

Kilo means thousand or 1000 or 10^{3}

Milli means thousandth or .001 or 10^{-3}

Micro means millionths or .000001 or 10^{-6}

Micro-micro means millionth part of a millionth part or .000000000001 or 10^{-12}.

Thus:

3 megohms	$= 3 \times 10^{6}$ ohms.
413 kilocycles	$= 413 \times 10^{3}$ cycles.
.3 milliamperes	$= .3 \times 10^{-3}$ amperes.
8 microfarads	$= 8 \times 10^{-6}$ farads.
10 micro-microfarads	$= 10 \times 10^{-6} \times 10^{-6} = 10 \times 10^{-12}$ farads.

Also 700000 ohms = $.7 \times 10^{6}$ ohms or .7 megohms.

4700 volts = 4.7×10^{3} volts or 4.7 kilovolts.

.0000472 amps = 47.2×10^{-6} amps or 47.2 microamps.

We will now apply powers of ten to solve the problem given in Example 1 under powers of 10.

This problem is:

$$F = \frac{.159}{\sqrt{.00015 \times .000000000004}}$$

$$= \frac{.159}{\sqrt{1.5 \times 10^{-4} \times 4 \times 10^{-12}}} = \frac{.159}{\sqrt{6 \times 10^{-16}}}$$

$$= \frac{.159}{\sqrt{6 \times 10^{-16}}} = \frac{.159}{2.45 \times 10^{-8}} = \frac{.159 \times 10^{8}}{2.45}$$

$$= \frac{15.9 \times 10^{6}}{2.45} = 6.5 \times 10^{6}$$

The powers of 10 will save many minutes in the solution of most electronics problems. You are strongly advised to study this assignment several times until you are completely familiar with the use of these powers of ten.

Mathematical Tables

For your convenience, we are including a mathematical table at the end of this assignment. This table gives the square, and square root of all numbers from 1 to 100.

By changing larger, or smaller numbers to numbers in this range, times a power of ten, this table can be used for a great many numbers. For example, if we wished to find the square root of 700, it could be changed to 7×10^2. The table tells us that the square root of 7 is 2.6458 and we know that the square root of 10^2 is 10. The square root of 700 is then 2.6458 x 10 or 26.458.

To find the square root of 990,000 we change it to 99×10^4. The square root of 99, from the table is 9.9499, and of course the square root of 10^4 is 10^2 or 100. The square root of 990,000 is then 9.9499 x 100 or 994.99.

To find the square root of .0069 we would change it to 69×10^{-4}. The square root of 69 is 8.3066 and the square root of 10^{-4} is 10^{-2}. The square root of .0069 is then 8.3066×10^{-2} or .083066.

To find the value of 760 squared we would change it to 76×10^1. $(76)^2$ is 5776 and ten squared is 10^2 or 100. 760 squared is then 5776 x 100 = 577,600.

For practice, use the table and powers of ten to solve the following problems:

1. $\sqrt{17}$	3. $\sqrt{8700}$	5. $\sqrt{.000043}$
2. $(170)^2$	4. $(19)^2$	6. $\sqrt{910000}$

Test Questions

Be sure to number your Answer Sheet Assignment 7.

Place your Name and Associate number on *every* Answer Sheet.

Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

In answering these mathematical problems *show all of your work. Draw a circle around your answer.*

Do your work neatly and legibly.

1. $14^2 =$
2. $\sqrt{121} =$ (use long-hand method)
3. $4^5 =$
4. $\sqrt{72} =$ (use mathematical table)
5. State in powers of 10.
   - (a) 3000
   - (b) .000009
   - (c) 1
   - (d) 9,000,000
6. What does the expression 10^3 mean?
7. Solve by using powers of 10:
   $10{,}000 \times 1{,}000 =$
8. $\dfrac{1}{27000 \times 3 \times 10^{-5}}$
9. Write in powers of ten.
   - (a) 17 megohms
   - (b) 3 milliamperes
   - (c) 72 micro-microfarads
   - (d) 270 Kilovolts
10. $98^2 =$ (use mathematical table)

MATHEMATICAL TABLE of SQUARES and SQUARE ROOTS

No.	Square	Sq. Root	No.	Square	Sq. Root
1	1	1.0000	51	2,601	7.1414
2	4	1.4142	52	2,704	7.2111
3	9	1.7321	53	2,809	7.2801
4	16	2.0000	54	2,916	7.3485
5	25	2.2361	55	3,025	7.4162
6	36	2.4495	56	3,136	7.4833
7	49	2.6458	57	3,249	7.5498
8	64	2.8284	58	3,364	7 6158
9	81	3.0000	59	3,481	7.6811
10	100	3.1623	60	3,600	7 7460
11	121	3.3166	61	3,721	7.8102
12	144	3.4641	62	3,844	7.8740
13	169	3.6056	63	3,969	7.9373
14	196	3.7417	64	4,096	8.0000
15	225	3.8730	65	4,225	8.0623
16	256	4.0000	66	4,356	8.1240
17	289	4.1231	67	4,489	8.1854
18	324	4.2426	68	4,624	8.2462
19	361	4.3589	69	4,761	8.3066
20	400	4.4721	70	4,900	8.3666
21	441	4.5826	71	5,041	8.4261
22	484	4.6904	72	5,184	8.4853
23	529	4.7958	73	5,329	8.5440
24	576	4.8990	74	5,476	8.6023
25	625	5.0000	75	5,625	8.6603
26	676	5.0990	76	5,776	8.7178
27	729	5.1962	77	5,929	8.7750
28	784	5.2915	78	6,084	8.8318
29	841	5.3852	79	6,241	8.8882
30	900	5.4772	80	6,400	8.9443
31	961	5.5678	81	6,561	9.0000
32	1,024	5.6569	82	6,724	9.0554
33	1,089	5.7446	83	6,889	9.1104
34	1,156	5.8310	84	7,056	9.1652
35	1,225	5.9161	85	7,225	9.2195
36	1,296	6.0000	86	7,396	9.2736
37	1,369	6.0828	87	7,569	9.3274
38	1,444	6.1644	88	7,744	9.3808
39	1,521	6.2450	89	7,921	9.4340
40	1,600	6.3246	90	8,100	9.4868
41	1,681	6,4031	91	8,281	9.5394
42	1,764	6.4807	92	8,464	9.5917
43	1,849	6.5574	93	8,649	9.6437
44	1,936	6.6332	94	8,836	9.6954
45	2,025	6.7082	95	9,025	9.7468
46	2,116	6.7823	96	9,216	9.7980
47	2,209	6.8557	97	9,409	9.8489
48	2,304	6.9282	98	9,604	9.8995
49	2,401	7.0000	99	9,801	9.9499
	2.500	7.0711	100	10,000	10.0000

Electronics
Radio
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UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

MAGNETS AND ELECTROMAGNETS **ASSIGNMENT 8**

ASSIGNMENT 8

MAGNETS and ELECTROMAGNETS

In Assignment 5 we studied the effects produced by an electric field. We found that a charged body was surrounded by a region wherein other objects were attracted. We said that an *electric field of force* existed in this region. The law concerning electric charges, and of course the electric field surrounding the charged bodies, is that *like charges repel and unlike charges attract.*

In this assignment we are going to study the *magnetic field of force.*

Everyone is familiar to a certain extent with the *magnetic field of force,* or as it is commonly called, *magnetism.* Most of us have at some time or other experimented with small magnets, used them to pick up nails, small bits of iron, etc. Magnetism makes a fascinating plaything, but it is also very important in our everyday life. It is used in the compasses which guide the ships at sea, in the electrical generators which supply the electrical power for our homes, in our radio and television receivers and in countless other applications.

Many centuries ago, the Greeks learned that certain pieces of ore possessed the ability to attract particles of iron. Since this was a very mysterious happening, pieces of this ore were carried as good luck charms. No practical application was made of magnetism for several centuries until it was found that if an elongated piece of this ore was suspended on a string, it would always align itself in a northerly direction. For this reason the ore was called *"lodestone"*, meaning "leading stone". The first compasses were made in this fashion. It was later discovered that pieces of iron could be magnetized by "stroking" a lodestone with the piece of iron. These pieces of iron, after being magnetized, would act as magnets themselves, and could be used for compasses. A piece of iron (or steel) which holds its magnetism for a long period of time is called a *permanent magnet.*

Let us find some of the characteristics of a permanent magnet. A permanent magnet, in the form of a bar, has two ends. These ends are called the *poles* of the magnet. The end which will point in a northerly direction, if the magnet is allowed to rotate, is called the *North-seeking pole,* or *North pole.* The other end of the magnet is called the *South-seeking pole,* or *South pole.*

If a small piece of iron is brought close to a permanent magnet, the magnet will attract the piece of iron, and "draw" the iron to it. This happens while the magnet and piece of iron are still separated. The force from the magnet extends into the air surrounding the magnet. This region in which the magnetic force acts is called the *magnetic field of force,* or more often the *magnetic field.* This magnetic field is usually considered to exist in the form of lines of force which leave the magnet at the north pole and return at the south pole. This is illustrated in Figure 1. Notice in this figure that the lines of force are concentrated at the ends of the magnet and spread out near the center of the magnet. The north pole on this magnet is marked N, and the south pole is marked S. If a bar magnet is placed under a piece of paper, and iron filings are sprinkled on the paper, the iron filings will arrange themselves in a pattern as shown in Figure 1 (without the arrowheads of course).

There are two general classifications of materials as far as magnetism is concerned; magnetic and non-magnetic. A magnetic material is one which will be attracted by a magnet. Iron and steel are the best known magnetic materials.

Nickel and cobalt are also attracted by a magnet, but to a lesser degree. All other materials are non-magnetic. For example, a piece of copper or silver is unaffected if brought close to a magnet. There are a few materials which are actually slightly repelled by a magnetic field. This action, however, is so weak, that it is of no practical value.

The fundamental law of magnetism is: *Like poles repel and unlike poles attract.* This is the phenomenon which makes the magnet act as a compass, or "point to the north". The earth itself is a magnet. The two magnetic poles of the earth are located within a few hundred miles of geographic poles. The entire earth is surrounded by the magnetic field of this giant magnet. When another magnet is pivoted so that it is free to rotate, the *north seeking* pole of the magnet will be attracted by the earth's magnetic pole near the north geographic pole. The magnet or compass will point to the earth's magnetic pole. The law of magnetism states that the *unlike poles* attract, therefore the magnetic pole located near the north geographic pole is actually a south magnetic pole since the north poles of all the compasses are attracted by this magnetic pole.

To further demonstrate the laws of magnetism, let us look at Figure 2. At (a) in this figure we see a small compass. The north pole of this compass is shown darkened so that it can be determined which pole of the compass is the north pole. In (a) the compass is acted upon by the earth's magnetic field, and the north pole of the compass points north. In (b) of this figure the compass is shown close to the north pole of a permanent magnet. The field of this permanent magnet is much stronger than the earth's magnetic field, so the compass rotates on its axis and the south pole of the compass points to the north pole of the magnet. In (c) of this figure the compass is brought close to the south pole of a magnet. Now the north pole of the compass is attracted by the south pole of the magnet.

The attraction of unlike poles and repulsion of like poles is due to the action of the magnetic fields. In Figure 1 we saw the pattern of the magnetic field around a bar magnet. In Figure 3 we see the pattern of the magnetic field if two bar magnets are held with their north poles adjacent. Notice how the fields oppose each other, trying to force the magnets apart.

Figure 4(a) shows the field of force around the ends of two bar magnets with their opposite poles adjacent. Notice that in this case the lines of force do not repel each other, but aid each other. The magnetic field between these two unlike poles is much stronger than it would be around the poles of either of the bar magnets, if they were not close together. One way then of obtaining a strong magnetic field is to bring two unlike poles close together. This can be done with two bar magnets as illustrated, but can be accomplished more simply by bending a single bar magnet in the middle, and making it in the shape of a horseshoe. This shape of magnet is used in most meters which are used to measure d-c current and voltage. A typical horseshoe magnet, and a diagram of the field of force around it, is shown in Figure 4(b).

A strong magnetic field is desirable since it is a field of *force* and if we have a stronger field we can do more work with it. We could pick up heavier pieces of iron, etc., than we could with a weak field. When a magnet is used in a meter, a stronger field will make the meter more sensitive. That is, for the same amount of current, the meter deflection will be greater.

A number of theories have been advanced to explain magnetism. The latest theory, and the one which appears most logical, fits in very well with the electron theory. According to this theory, the atoms or molecules in all matter are small magnets. In an unmagnetized piece of material the molecular magnets are arranged in a random manner. This is shown in Figure 5(a). The net result of these small magnetic fields is zero. When this bar becomes magnetized, the molecular magnets are lined-up as shown in Figure 5(b). The magnets are now aiding each other, and their fields all add up to produce a strong magnetic field about the bar.

Most permanent magnets are made from hard steel. In such a material, it is difficult to magnetize the bar, or line-up the molecular magnets, but after they are lined-up they will hold this position for long periods of time. If a piece of soft steel or iron is magnetized, it is a simple matter to align the molecular magnets, but when the magnetizing force is removed, the molecular magnets return readily to their original position and the bar does not retain its magnetism. It is possible to magnetize a piece of iron or steel by stroking it with another magnet. We will soon discuss a much simpler and more effective way of doing this.

Up to this point we have discussed only permanent magnets, Permanent magnets are used in meters, but very few applications of permanent magnets will be found in electronics or television circuits. There is another form of magnetism which plays an important part in electronics and television. This is the *electromagnet*. An electromagnet is a magnetic field which is produced by electric current.

Figure 6 shows a large electromagnet which is used for handling scrap iron. The operator lowers the large disc on the end of the boom over the scrap metal and closes a switch on his control panel. The disc becomes a very powerful magnet and attracts the scrap iron, holding it securely. Then the operator moves the vehicle to the desired location and opens the switch on his control panel. The electromagnet loses its magnetism and drops the scrap iron.

Figure 7 shows a very common form of electromagnet. It is a doorbell. When you press the doorbell switch, current flows through the circuit from D, through the coils of wire, and through the contact screw to B. This current flow causes the coils to become magnets and they attract the soft iron armature. This armature is held away from the magnets by spring tension, but when the coils become electromagnets the armature moves to the right, toward the magnets, and the hammer strikes the bell. If the coils remained electromagnets the hammer would remain against the bell, but this does not happen because as the armature moves to the right, the circuit is broken and current no longer flows through the coils. The circuit is broken because, as the armature moves to the right, the movable contact which is fastened to the armature also moves to the right, and is no longer touching the contact screw. This opens the circuit, current no longer passes through the coils, and they were no longer magnetized. The spring tension returns the armature to its original position. After the armature returns to its original position, the entire cycle repeats itself. Study Figure 7 to satisfy yourself that you see just how this action takes place.

These two examples were shown to give an idea of what happens, before we find out how it happens. We find from these two examples that magnetism can be produced by passing an electric current through a coil of wire. When the current stops flowing, the electromagnetic field no longer exists.

Now let us find out how this electromagnetic field is produced. If a piece of wire is connected to a battery as shown in Figure 8, current will flow through the wire in the direction indicated. This wire will be encircled by a magnetic field. If a small compass is passed around the wire as indicated in Figure 8, the compass needle will take the positions indicated. If the connections to the battery are reversed, the current will be flowing through the wire in the opposite direction, and the compass will point in the opposite directions to those indicated in Figure 8. In each case the compass indicates the direction of the surrounding magnetic field. The magnetic field around the wire is in the form of concentric circles.

If a piece of wire is thrust through a sheet of paper as shown in Figure 9, and is then connected to a battery, a magnetic field will encircle the wire. If iron filings are sprinkled on the sheet of paper, they will align themselves in a pattern as shown in Figure 9.

If we know the direction of electron flow through a wire, we do not need compasses to determine the direction of the magnetic field. Check the following rule with direction of magnetic field indicated by the compass needles in Figure 8. *If we grasp the conductor with our left hand so that our thumb points in the direction of electron flow, the remaining four fingers of our left hand will curl in the direction of the magnetic field around the conductor. This is called the Left Hand Rule.* Remember, the magnetic field is considered "to flow" from north to south outside of the magnet.

In Figure 10 we used the Left Hand Rule to determine the direction of the field around the conductor at five different locations. Check the position of arrowheads on the tiny loops until you are satisfied that they are correct.

If we double the amount of current flowing through the wire, the magnetic field will be twice as strong. The best way to obtain a strong field, however, is to wind the wire in the form of a spiral or coil.

In Figure 11 we have made a coil with the wire. Check each loop around the wire. Has every loop been shown with its arrowhead in the correct direction? Notice, that inside the coil the field direction is from right to left at every point. If we wind the "turns" of our coil more closely together (Figure 12), we have most of the magnetic field passing straight through the center of the coil and out the left hand end. The left end of the coil acts like the North Pole of a permanent magnet because the field is leaving that end. If we reverse the direction of current in the coil, the left end of the coil will be a South Pole.

It is easy to see what happens when we wind the wire in the form of a coil. Some of the magnetic field will still encircle individual wires in the coil. However, the field produced by adjacent wires are in opposite directions between the wires and tend to cancel each other. Most of the field then will encircle the coil, end to end, as shown in Figure 12.

Another application of the Left Hand Rule makes it easy to determine which end of a coil will have a north magnetic pole.

If the coil is grasped with the left hand so that the fingers point in the direction of the current flow, the thumb will point to the north pole of the electromagnet. Apply this rule to the coil in Figure 12, and see if you agree with the marking of the poles of the electromagnet in the diagram.

The strength of the magnet field about a coil may be increased by adding more turns to the coil, or by increasing the amount of current flowing through it.

The coil of copper wire in an electromagnet is used to produce a magnetic field. This magnetic field, by itself, will not be strong enough to operate the doorbell buzzer, to say nothing of the steel yard electromagnet. We have to add iron for a magnetic core in order to obtain very strong magnetic fields. The addition of an iron core to an electromagnet may increase the magnetic field as much as 100 or more times.

As was pointed out in the discussion of permanent magnets, each molecule of a material has its own magnetic field. If a piece of soft iron is inserted in the coil of an electromagnet and current is caused to flow through the coil, the magnetic field of the coil will pass through the soft iron core. This magnetic field will cause the molecular magnets in the soft iron core to "line-up" as shown in Figure 13(b). The "lining-up" of these molecular magnets in the core material will produce a magnetic field much greater than that produced by the coil alone.

Soft iron is used as the core of electromagnets because it is easy to line-up the molecular magnets in a piece of soft iron. Also, when the electrical circuit is broken by opening the switch, as shown in Figure 13(a), the molecular magnets return to their original positions, and the electromagnet loses its magnetism. Thus, in the steel yard electromagnet, the scrap iron will be dropped when the operator opens the switch on his control panel, and in the doorbell the armature will return to its original position when the contact is opened.

It was mentioned previously, that there is a simple method of producing permanent magnets. This is done by placing a piece of hard steel inside a coil of wire and passing a *very strong* current through the coil. A very strong current is needed because a strong magnetic field is required to line up the molecular magnets in the hard steel. After this hard steel has been magnetized, it will retain its magnetism after the current in the electromagnet is stopped.

We will sum up the fundamental principles we have covered so far:

1. A magnetic field is the field of force which surrounds a magnet.
2. A magnet has two poles, North and South.
3. Like magnetic poles repel each other.
4. Unlike magnetic poles attract each other.
5. Permanent magnets are made with hard steel and retain their magnetism.
6. Any piece of wire carrying an electric current has a magnetic field around it.
7. We can increase the magnetic effect of an electric current by increasing the amount of current or by winding the wire in the form of a coil, and, in this case, the magnet so produced is called an electromagnet.
8. If we place a soft iron core in the coil of wire carrying current, we can obtain very strong magnetic fields. The soft iron core becomes magnetized and adds its strong magnetic field to the magnetic field of the coil.
9. The Left Hand Rule can be used if we need to know which end of a coil is the North Pole and which is the South Pole.

Units of Measurement of Magnetism

We have seen that the *magnetic line of force* is a closed loop or path, passing from the north pole to the south pole of a magnet. The space through which these lines of force act is called the *magnetic field.*

To a great extent, the action of a magnetic circuit can be compared to the action of an electric circuit. We learned in Assignment 6 that in an electric circuit, the current flowing was dependent upon two things, the e.m.f., or voltage and the resistance. To state this as a formula we may write:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

Notice that this means that the amount of effect produced (current flow) is equal to the force applied (volts or e.m.f.) divided by the opposition (resistance).

In a magnetic circuit, the effect produced is the magnetic lines of force, or *flux* as it is commonly called. The magnetic force, that is, the force which tends to produce magnetism, is called the *magnetomotive force* (abbreviated mmf). The opposition to the passage of magnetic lines of force, or flux, through a material is called the *reluctance* of the material.

The formula for magnetic circuits is:

$$\text{Flux} = \frac{\text{Magnetomotive Force}}{\text{Reluctance}}$$

Notice that in this formula, the effect produced is equal to the force applied, divided by the opposition.

The unit of magnetic flux is the *maxwell*.

The unit of magnetomotive force is the *gilbert*.

Reluctance is measured in gilberts per maxwell.

These units were named for famous scientists who devoted a great deal of time to the study of magnetism.

If we examine the formula for magnetic circuits carefully we are able to see the reason for several things that have been mentioned. For example, it was stated that the magnetic field (flux) around a coil could be increased, if the current flowing through the coil were increased. The formula shows that this would be true, for with an increased current through the coil the mmf would be greater, and consequently the flux would be increased. It was also stated that more flux would exist if an iron core were placed in a coil of wire carrying a current. The iron core offers less opposition to the magnetic lines of force, or in other words, has a smaller reluctance, than air. It can be seen that if the reluctance is made smaller in the formula, that the flux will increase.

There are two other terms which are used when considering magnetic materials. These are *permeability* and *retentivity*.

Permeability is just the opposite of reluctance. Reluctance is a measure of the opposition offered to magnetic lines of force. Permeability is a measure of the ease with which lines of force can be set up in a material. The more permeable a material is, the better it will "conduct" magnetic lines of force, and consequently the better core it will make for an electromagnet. The permeability of air and all non-magnetic materials is 1. The permeability of iron is about 50. Silicon steel has a permeability of about 3000, and some special magnetic materials have permeabilities of as high as 10,000. This means that if a core of this special magnetic material is added to a coil of wire which is carrying current, the magnetic field will be increased 10,000 times.

Retentivity is a measure of the ability of a piece of material to retain its magnetism, after the magnetizing force is removed. For some applications, high retentivity is desirable, and for some applications, low retentivity is desirable. The material used for permanent magnets should have high retentivity. After these pieces of material have been magnetized, it is highly desirable for them to retain their magnetism for many years. The cores of most electromagnets are made of material with low retentivity. This is because in most cases, it is desirable for the electromagnet to lose all of its magnetism when the current flow to the coil is stopped. For example, when the operator of the steelyard crane shown in Figure 6, opens the switch on his control panel, the current to the coil is stopped, and the electromagnet should become demagnetized, so that the scrap iron can be dropped.

Let us now study a few applications of the electromagnetic principles. One application of electromagnets is in relays.

Relays

Relays are switches which may be controlled from some remote position. They consist of an electromagnet and one or more sets of contacts. Three typical relays are shown in Figure 14. Examine these pictures and identify these parts on the relays.

(1). Electromagnet. This is the circular shaped part near the center of each. These electromagnets are wound with a large number of turns of wire and have soft iron cores.

(2). Armature. This is the movable part of the relay which is held away from the electromagnet by spring tension.

(3). Contacts. There are two parts to each contact, the movable contact and the fixed contact.

Notice the contact on the relay shown in Figure 14(a). The *fixed* contact is mounted rigidly on the insulated mounting block. When the electromagnet on this relay is *not* turned on, the movable contact is held away from the *fixed* contact by the spring tension on the armature. When the electromagnet is turned on, or energized, as the act of turning on an electromagnet is commonly called, the movable contact is pulled down with the armature and is held against the fixed contact. Such a set of contacts is called a *normally open set of contacts.* It is possible to have a relay with contacts which are held closed by the spring tension, and then are opened by the action of the electromagnet. These contacts are called *normally closed contacts.* The relay shown in Figure 14(b) has a combination of these two types of contacts. Let us see how it would work. The movable contact is on the armature. When the electromagnet is not energized, the spring tension holds the movable contact against the top fixed contact. This contact is normally closed. When the relay coil becomes energized, the armature pulls down and opens this top contact circuit, but at the same time the movable contact is pulled against the lower contact and closes this circuit. The relay in Figure 14(c) has two sets of contacts (only one set is completely visible in the picture). Each of these sets has one normally open and one normally closed contact.

Relays may be purchased with almost any arrangement and number of contacts. They are used very widely in transmitters and in electronic equipment.

Figures 15(a) and 15(b) shows a very simple circuit using a relay. In Figure 15(a) the switch in the *control circuit,* in series with the electromagnet coil and the battery, is open. Therefore, there is no current flowing through the coil and it is not magnetized. The contacts in the *controlled circuit* are "open" and no current flows through the lamp.

In Figure 15(b) the switch in the control circuit is closed. Current flows through the electromagnet coil. When the electromagnet becomes magnetized, it draws the armature toward it, to the left in the drawing, and closes the contact in the controlled circuit. (Current flows from the battery in the controlled circuit, through the closed contact and the lamp, lighting the lamp.) To turn the lamp off it is only necessary to open the switch in the control circuit.

The question might arise, why not just put a switch in the lamp circuit and not use a relay. The answer to this is that the switch in the control circuit is a small switch and will handle only a small current. If the lamp in the circuit is a large lamp it will have a large current flowing through it, and this large current would ruin the small switch. There is also the matter of convienence to be considered. The switch may be located remotely from the relay, thus a few small switches on a control panel may control a group of large relays at some remote point.

Let us show another example where a relay would be used. In a two-way radio installation in a police car there is a receiver and a transmitter. They are each drawing current from the battery, and will discharge the battery rapidly if they are both turned on at the same time. There is no reason for having them both on at the same time, since it is not possible to transmit and receive at the same time. This problem could be solved by having separate switches on the transmitter and receiver and turning one on and the other off each time, but this is very inconvienent, and sooner or later the operator will fail to turn one off while the other is on and will discharge the battery. This could be solved very simply by using a relay and a circuit as shown in Figure 16. The switch in the control circuit is mounted on the microphone. The B+ (this is the positive high voltage) from the power supply is connected to the movable contact on a relay. The normally closed contact is connected to the receiver, and the normally open contact is connected to the transmitter. When the switch on the microphone is not closed, the receiver is operating. When the operator wants to transmit he merely closes the switch on the microphone, usually by pressing a button, and the receiver will be turned off and the transmitter turned on. The relay does the job convienently and will never "forget" and leave both units on at the same time.

Motor and Generator Action

Motors, generators and most electric meters depend on magnetic fields for their operation. In Figure 17 we have shown a core that is being magnetized by a coil which is carrying current. We have shown the North and South Poles. In an actual case we might have several hundred (rather than 3) turns in the coil. We know that there is a magnetic field in the air between the North and South Poles. We say that the field is from North to South in this "air-gap". If we dip our hands in salt water to make good electrical contact we can perform the following experiment.

Take a piece of heavy copper wire (about 1/4 inch in diameter) and grasp one end in each hand. Push the wire through the magnetic field as shown. If the magnetic field is strong enough you can get quite a "shock". When you withdraw the wire you will again get a shock. The faster you move the wire through the magnetic field, the stronger the shock. Moving the wire through the field has caused a voltage to be induced in the wire. Let us repeat this statement. Any time a conductor is moved through a magnetic field, a voltage will be induced (or developed) in the conductor.

We can perform the same experiment in a safer and more accurate fashion. In Figure 18 we have a small horseshoe permanent magnet. (We could use a weak electromagnet.) We have connected the two test leads of a sensitive galvanometer to the ends of a loop of wire. (A galvanometer is a sensitive voltmeter.) The galvanometer needle will kick in one direction when we pass the "loop" down through the magnetic field. The needle will kick in the opposite direction as we bring the loop back up through the field. The speed with which we move the wire loop through the field will determine how strong a kick we give the needle in the galvanometer.

Huge generators in power-houses operate on this one simple principle. In most large generators the wire "stands still" and the magnetic field is made to move. The effect is the same however. All we need is a conductor, a magnetic field and motion. The galvanometer in Figure 18 would register if we held the wire in one position and moved the magnet up and down.

In Figures 17 and 18 we have examined the fundamentals of generator action. A wire has been moved through a magnetic field and a voltage has been induced in it.

Figure 19 illustrates motor action. Here again we have a magnetic field. We can use either a permanent magnet or an electromagnet to obtain the magnetic field. We use a battery to force an electric current through the wire. We will not have to move the wire this time. The wire will move itself. It isn't difficult to see why. Why did the compass needle move when we placed it near one of the poles of a magnet in Figure 2? It was the action of *two* magnetic fields.

In Figure 19 we have two magnetic fields. We have a strong field from the North to South pole of the large magnet. We also have a magnetic field around the wire which is carrying a current. In Figure 20 we have an enlarged view of the wire in the magnetic field. The arrows indicate the direction of the magnetic fields. Assume that the current in the wire is "into the paper". By the Left Hand Rule then, the field around the wire is counter-clockwise as shown. The interaction of the two fields causes the lines of force between the North and South poles of the magnet to be distorted, or bent, as shown in Figure 20(a). One property of magnetic lines of force is that they attempt to establish themselves in as short a path as possible. They are often considered to be elastic. Visualize the lines of force between the poles of the magnet as stretched rubber bands. If they were stretched out of shape as shown, they would force the wire to the right in the diagram. That is just what the magnetic lines of force do. They attempt to shorten their length and in so doing, force the conductor to the right. This movement to the right will continue until the conductor is forced to the extreme right edge of the magnetic field as shown in Figure 20(B).

Figures 19 and 20 have demonstrated fundamental motor action. A wire carrying current is placed in a magnetic field, and is caused to move by the interaction of two magnetic fields.

Action of a D-C Meter

In previous assignments we spoke of meters which are used to measure d-c current. These instruments operate on the principle of the interaction of two magnetic fields. The principle of the operation of meters is shown in Figure 21.

A permanent magnet is used to obtain one magnetic field. A coil of wire is mounted on pivots and is located in the field of the permanent magnet. Small spiral springs on the pivot shaft hold the coil at right angles to the magnetic field when no current is flowing through the coil. When current is passed through the coil, it becomes an electromagnet and its magnetic field attempts to line up with the field of the permanent magnet. This causes the coil to rotate. A pointer on the pivot shaft indicates the amount of current flowing through the coil. With no current flowing, the meter reads zero, and as the amount of current is increased the pointer moves up the scale of the meter. The more current flowing through the coil, the farther the coil will rotate against the spiral springs. When as much current as the meter is designed to handle flows through the coil, the coil will be lined up across the air gap in the permanent magnet so that the magnetic fields will be lined up. Remember that the magnetic field of a coil is through the entire coil as shown in Figure 12.

These explanations of generator action, motor action, and action of d-c meters show only the fundamentals of the actions. Each of these subjects will be studied in detail later in the training program.

In this assingment we have learned the basic principles of magnetism. In our progress through the training period we shall learn to apply these basic principles in the study of various electronics circuits. We will learn that these magnetic effects make possible the selection of the desired radio station from the thousand on the air, make possible the operation of electronics equipment from the 110V a-c power lines, and in fact, make electronics possible.

Test Questions

Be sure to number your Answer Sheet Assignment 8.

Place your Name and Associate Number on *every* Answer Sheet.

Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. Is the magnetic field *strongest* or *weakest* at the poles of a permanent magnet?
2. Will like magnetic poles *repel* or *attract* each other?
3. Will the magnetic field of an electromagnet become stronger or weaker if more current is passed through the coil?
4. How can we increase the magnetic field of a coil of wire without changing the number of turns on the coil or the current?
5. (a) What happens if a piece of iron is brought close to a permanent magnet?

   (b) What happens if a piece of aluminum is brought close to a magnet?
6. In the circuit shown in Figure 22, will the right end of the coil be the *North* or the *South* pole of the electromagnet?
7. What is a relay?
8. Does a straight piece of wire carrying a current have a magnetic field?
9. What happens when we move a copper wire through a magnetic field?
10. What happens when we pass a current through a copper wire which is located in a magnetic field?

induced

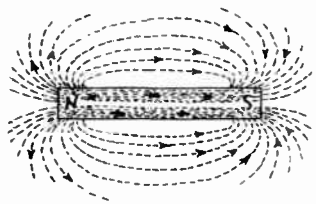


FIGURE 1

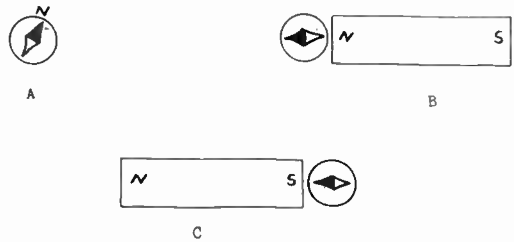


FIGURE 2

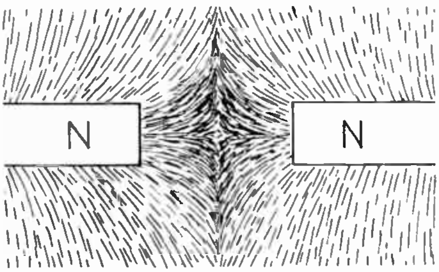


FIGURE 3

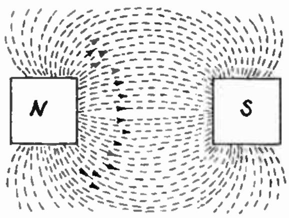


FIGURE 4 - A

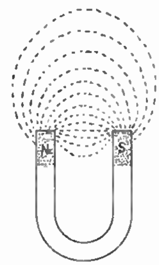


FIGURE 4 - B

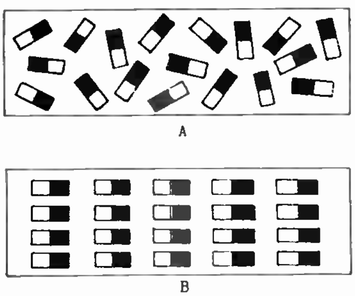


FIGURE 5

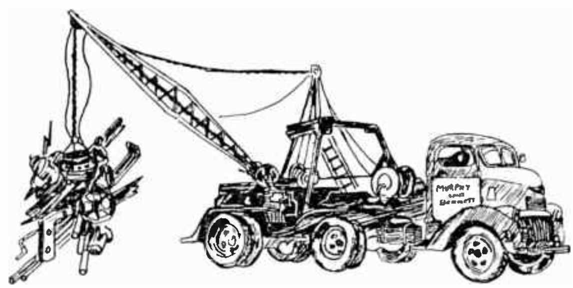


FIGURE 6

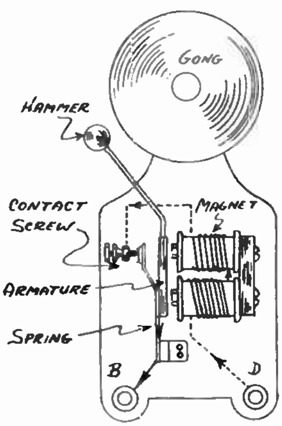


FIGURE 7

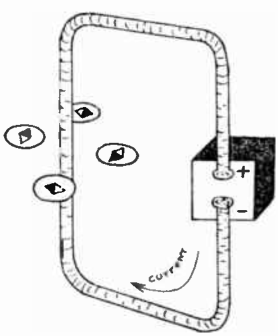


FIGURE 8

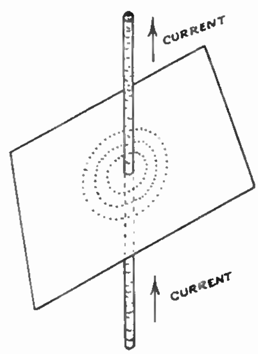


FIGURE 9

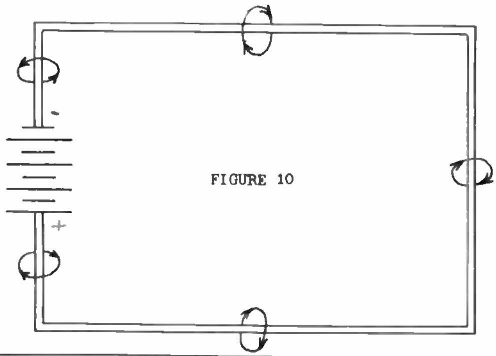


FIGURE 10

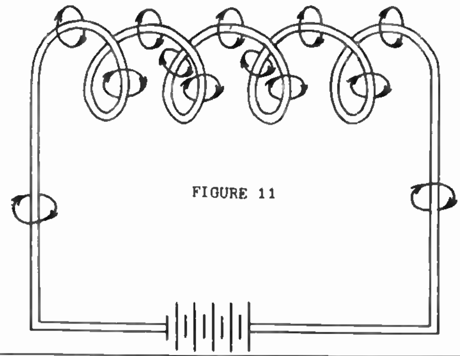


FIGURE 11

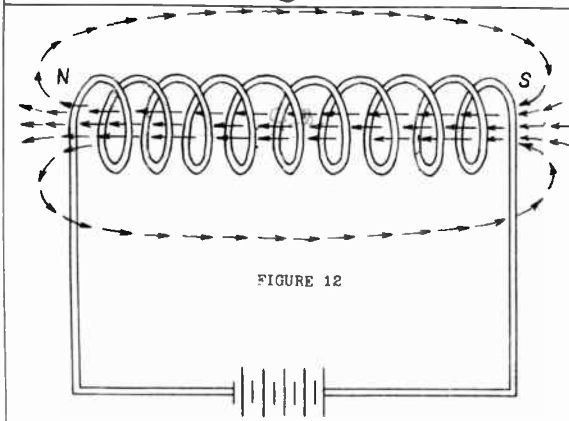
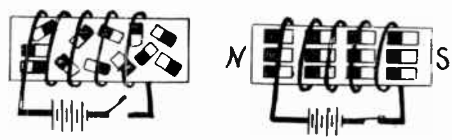


FIGURE 12



A

B

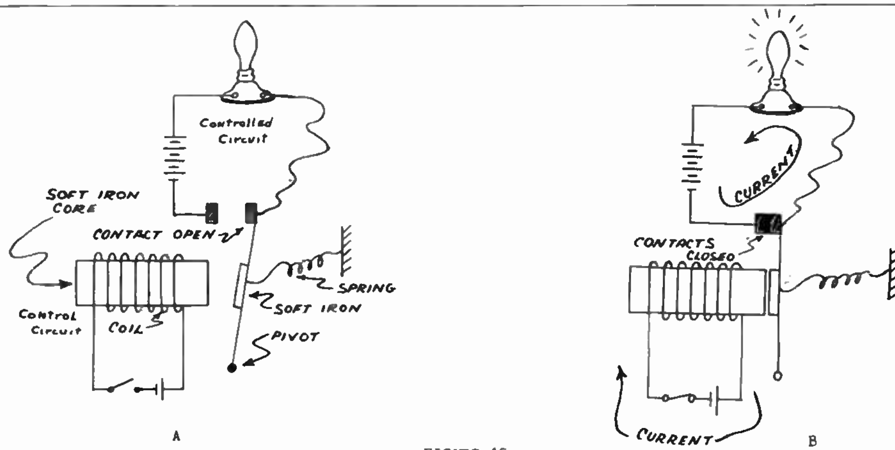
FIGURE 13

A

B

FIGURE 14

C



A

FIGURE 15

B

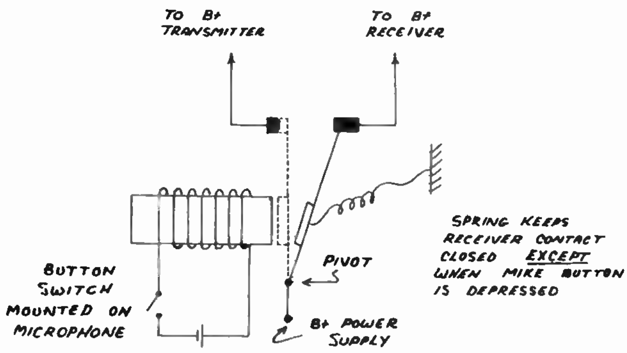


FIGURE 16

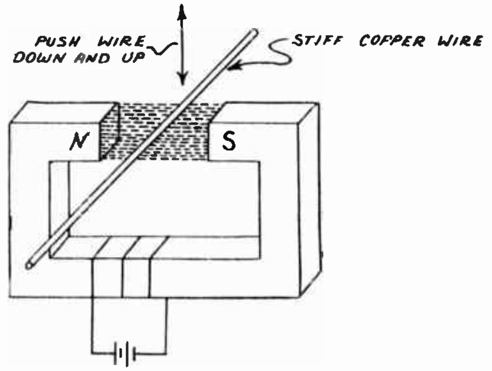


FIGURE 17

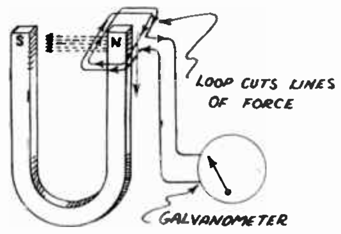


FIGURE 18

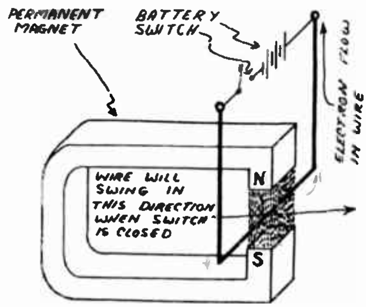


FIGURE 19

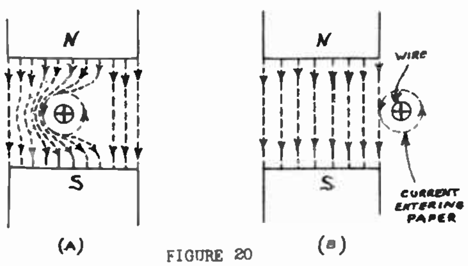


FIGURE 20

CHECK THE DIRECTION OF CURRENT FLOW AND MAGNETIC FIELD FOR THE MOVABLE COIL. ARE YOU CERTAIN THE COIL IS POINTED IN THE RIGHT DIRECTION?

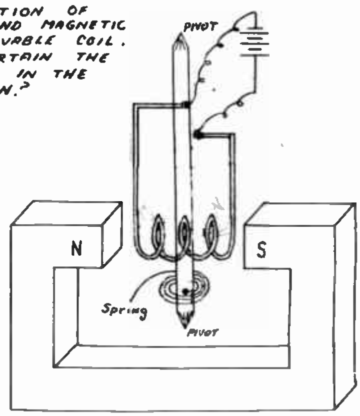


FIGURE 21

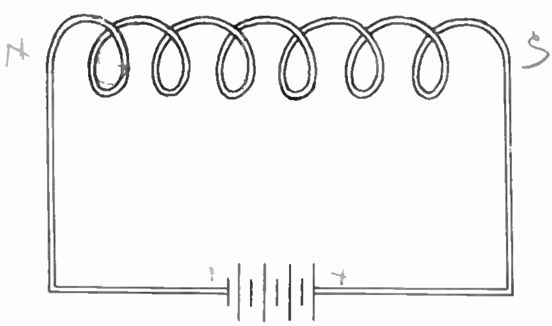


FIGURE 22

Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

OHM'S LAW---PARALLEL CIRCUITS

ASSIGNMENT 8B

ASSIGNMENT 8B

OHM'S LAW--PARALLEL CIRCUITS

Of course, the primary aim of this training program is to provide you with a thorough understanding of the complete circuits of electronic equipment. For these complete circuits to be understood, however, it is first necessary to learn about basic circuit arrangements. That is the purpose of this assignment, which consists of a continuation of the information concerning Ohm's Law as applied to d-c circuits. It will be recalled that this subject was first discussed in Assignment No. 6 wherein the basic concepts of Ohm's Law and the applications of Ohm's Law to series circuits were discussed in detail. The Associate is advised to review Assignment No. 6 carefully so that the information in that assignment will be well in mind before proceeding with this assignment.

There are three fundamental factors in a d-c circuit which must be considered. These are; (1) the electromotive force or voltage, (2) the current, and (3) the resistance. The current is the motion of the free electrons around an electrical circuit, the electromotive force is the electrical force which is applied to the circuit which causes current to flow, and resistance is the measure of opposition offered to the flow of the current. There is a definite relationship between the amount of voltage applied to a circuit, the resistance present in a circuit, and the current which flows in that circuit. This relationship is called Ohm's Law. This relationship is ordinarily written in the form of Ohm's Law equations as follows:

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

Where I equals current in amperes, R equals resistance in ohms, and E equals voltage in volts.

There are three circuit arrangements which may be employed. These are; series, parallel, and series-parallel. Figure 1 illustrates a battery and three resistors connected in these three circuit arrangements. Figure 1(A) illustrates a series circuit in both the pictorial and schematic form. Figure 1(B) illustrates the parallel circuit and Figure 1(C) illustrates the series-parallel circuit.

The current paths should be traced in a circuit to determine whether the arrangement employed is series, parallel, or series-parallel. If only one path is provided for the current from the negative terminal of the voltage source through the circuit to the positive terminal of the voltage source, the arrangement is a series circuit. For example, note in Figure 1(A) that the current leaves the negative terminal of the battery, flows through R_1, then through R_2, then through R_3, and returns to the positive terminal of the voltage source. Since all of the current flows through each component of the circuit this arrangement is a series circuit.

The current paths illustrated by the dotted lines in Figure 1(B) show that this circuit represents an entirely different arrangement than that of Figure 1(A). Notice that a portion of the current leaves the negative terminal of the battery, flows through R_1 and returns to the positive terminal of the battery. Another portion of the current leaves the negative terminal of the battery, flows through R_2 and returns to the positive terminal of the battery. At the same time a third portion of current leaves the negative terminal of the battery, flows through r_3 and returns to the positive terminal of the battery. It is evident therefore, that more than one path is provided for the current in the circuit of Figure 1(B) and this arrangement is called a parallel circuit.

The arrangement illustrated in Figure 1(C) is called a series-parallel circuit, as a portion of this circuit consists of a parallel circuit, but this parallel circuit is in series with the remainder of the circuit. As illustrated by the current paths in Figure 1(C), a portion of the current leaves the negative terminal of the battery and flows through R_1. At this same time a portion of the current flows from the negative terminal of the battery through R_2 joining the current that flows through R_1 at the junction of these two resistors and R_3. The combined current then flows through R_3 and returns to the positive terminal of the battery. Thus, the parallel combination of R_1 and R_2 is in series with R_3. These three figures should illustrate the manner in which the current path, or paths, should be traced to determine whether a circuit is a series, parallel, or series-parallel arrangement.

In the discussion to follow, a number of parallel circuits will be considered. In order to demonstrate clearly the manner in which these circuits function, numerical examples will be used. It should be emphasized however, that the important consideration, in each case, is not the mathematics involved, but is, instead, the thorough understanding of the operation of each electrical circuit. The Associate should bear this fact in mind as he proceeds with the assignment.

Parallel Circuits

By definition, a parallel circuit is a circuit which provides two or more paths for the current. To understand how such a circuit functions, let us first analyze the operation of the three simple series circuits illustrated in Figure 2. Figure 2(A) shows a 12 ohm resistor connected to a 12 volt battery, Figure 2(B) shows a 6 ohm resistor connected to a 12 volt battery and Figure 2(C) shows a 4 ohm resistor connected to a 12 volt battery. Let us apply Ohm's Law to find the current flowing in each circuit.

In Figure 2(A)	In Figure 2(B)	In Figure 2(C)
$I = \frac{E}{R}$	$I = \frac{E}{R}$	$I = \frac{E}{R}$
$I = \frac{12}{12} = 1$ ampere	$I = \frac{12}{6} = 2$ amperes	$I = \frac{12}{4} = 3$ amperes

The foregoing calculations are examples of the application of Ohm's Law to series circuits as discussed in Assignment No. 6. In the circuits of Figure 2 a 12 volt battery was used in each instance. Let us now arrange a circuit as illustrated in Figure 3(A) so that the 3 resistors used in the circuits of Figure 2 are connected to a single 12 volt battery. It will be noticed that this forms a circuit similar to the one shown in Figure 1(B) and, since three paths are provided for the current, this forms a parallel circuit.

In the parallel circuit of Figure 3(A) the emf applied to each of the three resistors is 12 volts, just as in Figures 2(A), (B) and (C). For this reason the current which flows through each of the resistors in Figure 3(A) is the same as the current which flows through the corresponding resistor in Figure 2 - in other words, one ampere of current flows through the 12 ohm resistor, 2 amperes of current flows through the 6 ohm resistor and 3 amperes of current flows through the 4 ohm resistor.

Figure 3(B) illustrates a schematic diagram of the circuit of Figure 3(A) and the connecting leads have been shown in different sizes according to the current each is carrying. That is, one ampere of current flows through the 12 ohm resistor, two amperes of current flows through the 6 ohm resistor and 3 amperes of current flows through the 4 ohm resistor. Notice that the total current flowing from the battery is the sum of the individual currents. The total battery current is 1 + 2 + 3 = 6 amperes. Study this schematic diagram carefully until it seems logical to you that the 4 ohm resistor (smallest of the three resistors) passes the largest current. Remember that the resistance is the measure of opposition offered to the flow of electric current and therefore the smallest resistor offers less opposition than the others. The electrons moving up to point X find three possible paths to follow from X to Y. Part of the current flows through the 12 ohm resistor, part through the 6 ohm resistor and part through the 4 ohm resistor. Since the 4 ohm resistor offers the least opposition, the amount of current which flows through it is greater than that which flows through the 6 ohm resistor or the 12 ohm resistor.

In Figure 3 we have a 12 volt battery, and therefore have 12 volts of electrical pressure available for the circuit. The only resistors in the circuit are between points X and Y. All of the 12 volts will be applied to each of the three resistors; it should be emphasized, however, that we do not have 36 volts in the circuit. The same 12 volts is being applied across each of the three resistors. This will seem reasonable to you if you stop to consider the electrical wiring in your home. You can operate light bulbs, toasters, radios and electrical fans at the same time by connecting them to different outlets in the various rooms. Each appliance operates at 110 volts. The power company supplies the 110 volts at the fuse box. You are able to use that 110 volts in a variety of locations in the house because all of the outlets and receptacles are connected in parallel. This illustrates an important characteristic of parallel circuits. The same voltage is applied to the various branches of a parallel circuit.

In Figure 3(B) it will be noted that we have placed the value of current and voltage of each resistor in the circuit in a table. This is a convenient method of tabulating the conditions present in the various circuits to be analyzed in this assignment. This chart indicates that the emf applied to the 12 ohm resistor is 12 volts and the current that flows through this resistor is one ampere. Similarly the table indicates that 12 volts are applied to the 6 ohm resistor and a current of 2 amperes flows.

Figure 4 illustrates another parallel circuit. In this case, the emf applied to the circuit from the battery is 6 volts and four parallel paths are provided. Each of these paths consists of an 8 ohm resistor. As indicated in the accompanying table .75 ampere of current flows through each resistor. This can be checked by applying Ohm's Law as follows: $I = \frac{E}{R}$, $I = \frac{6}{8}$ = .75 ampere. How is it that the same amount of current flows through each of the four arms of Figure 4? This may be explained very easily. The current flowing between points A and B distributes itself evenly in the four arms because the four paths between points A and B are alike and thus all offer the same amount of opposition to the current. The total current from the battery, or the line current as it is often called, may be found by adding up the individual currents. Thus the line current is .75 + .75 + .75 + .75 = 3 amperes.

Figure 5 illustrates a parallel circuit in which three resistors are connected across the 100 volt power supply of a radio receiver. The three resistors have ohmic values of 10,000 ohms, 20,000 ohms and 50,000 ohms. To find the current flowing through the 10,000 ohm resistor Ohm's Law will be applied as follows:

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

$$I = \frac{100}{10,000}$$

I = .01 ampere or 10 milliamperes

Apply a similar method to determine the current flowing through resistor R_2 and resistor R_3 in the circuit of Figure 5 and check your answers against the values shown in the table accompanying this figure. Now find the total current which flows from the power supply and check your answer against the solution given at the end of the assignment.

There is one point which should be noted when examining Figures 3, 4 and 5. Notice particularly that since the line current is equal to the sum of the currents of the individual branches, it is always greater than the current of any of the parallel branches. This indicates that the resistance of the entire parallel network is always less than the resistance of any of the branches of that network. This point will again be emphasized presently.

Equivalent Resistance

In Assignment 6 it was mentioned that the equivalent resistance of a group of series resistors was a value of resistance which, when substituted for the group of resistors, would cause the same current to flow in the circuit. In a similar manner the equivalent resistance of a group pf parallel resistors is that value of resistance which, if substituted for the group of parallel resistors, would cause the same current to flow in the circuit. Since the current paths in a parallel circuit are entirely different than those in a series circuit it should be evident that the manner in which the equivalent resistance of parallel resistors is computed is different than the manner in which the equivalent resistance of series resistors is computed.

There are two ways of finding the equivalent resistance of parallel resistors. One of these methods is sometimes called the "total current method" and the other involves the application of an equivalent resistance formula. Let us first use the total current method and employ the circuit of Figure 3 to demonstrate its use. In finding the equivalent resistance by the total current method the first step is to find the current through each resistor as we did in Figure 3. Then the individual branch currents are added to obtain the total current, or line current. This has already been done in Figure 3 and the total current was found to be 6 amperes. The equivalent resistance of the parallel circuit of Figure 3 is that resistance which would cause the same amount of current to flow in the circuit. This value of current is 6 amperes in this case. To find the equivalent resistance we merely apply Ohm's Law using the total current as the value of I in the formula.

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

$$R = \frac{12}{6}$$

$$R = 2 \text{ ohms}$$

If we were to place a 2 ohm resistor across the 12 volt battery, 6 amperes of current would flow so 2 ohms is the equivalent resistance of the parallel circuit of Figure 3. Notice particularly that the equivalent resistance of the group of parallel resistors is less than any of the resistors forming the circuit.

Let us apply the total current method to the circuits of Figures 4 and 5 to determine the equivalent resistance. The current flowing in each resistance in the circuit of Figure 4 is .75 ampere and the total current is 3 amperes. To find the equivalent resistance Ohm's Law is applied as follows:

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

$$R = \frac{6}{3}$$

$$R = 2 \text{ ohms}$$

Once again note that the equivalent resistance of the parallel circuit is less than the resistance of any of the branches of the circuit.

The individual currents in Figure 5 have been computed and also the total current. Apply the method outlined above to determine the equivalent resistance of these three resistors and check your answer against the soltuion given at the end of the assignment.

the solution given at the end of the assignment.

In some cases it is desirable to redraw a parallel circuit and substitute the equivalent resistance in the circuit in place of the original parallel network. This is illustrated in Figure 6. The original circuit consists of two parallel 2 ohm resistors connected to a 4 volt battery. The REI table shown in this figure illustrates the fact that the current which flows through each of the resistors is 2 amperes. You are advised to apply Ohm's Law to the circuit to verify the amount of current illustrated in the REI table. Since the current which flows through each resistor is 2 amperes the total current drawn from the battery is 4 amperes. This total current can be used to determine the equivalent resistance of the parallel circuit as follows:

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

$$R = \frac{4}{4}$$

$$R = 1 \text{ ohm}$$

Figure 6(B) shows the equivalent circuit of Figure 6(A). In this case the equivalent resistance of 1 ohm has been substituted for the two parallel 2 ohm resistors. Notice in the circuit of Figure 6(B) that the current flowing from the battery, or as it is often referred to, the current drawn from the battery, would be identical with the current drawn from the battery of Figure 6(A), or 4 amperes. Thus the circuit of Figure 6(B) is said to be the equivalent circuit of Figure 6(A).

Figure 7(A) illustrates another simple parallel circuit in which a 4 ohm resistor and a 6 ohm resistor are connected in parallel across a 24 volt source of potential. Ohm's Law can be applied to the two branches to determine the current which flows in each and the results obtained may be tabulated in a REI table as shown. Check these figures to verify the fact that 6 amperes of current flows through the 4 ohm resistor and 4 amperes of current flows through the 6 ohm resistor. This would result in a total current of 10 amperes flowing from the battery. This value of total current may be used to determine the equivalent resistance of the 4 ohm and the the 6 ohm parallel resistors as follows:

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

$$R = \frac{24}{10}$$

$$R = 2.4 \text{ ohms}$$

Thus the equivalent circuit of Figure 7(B) can be drawn and a 2.4 ohm resistor substituted for the paralleled 4 ohm and 6 ohm resistors of Figure 7(A), since the current flowing from the battery in the circuit of Figure 7(B) would be the same as that flowing from the battery in the circuit of Figure 7(A). Notice once again in this circuit that the equivalent resistance of the two parallel resistors is smaller than the smallest parallel resistor. In other words, the effect of the parallel combination in the circuit of Figure 7(A) is to offer less resistance than that which would be offered by either of the resistors individually.

Finding Equivalent Resistance By Means Of Formulas

The means of determining the equivalent resistance of parallel resistors outlined above is very satisfactory. One advantage of this arrangement is that no new formulas are employed. All of the calculations involve the use of Ohm's Law only, which should by this time, be quite familiar to the Associate. There are, however, several formulas which may be used to determine the equivalent resistance of parallel resistors. The first of these formulas is the simplest and may be used only when the resistors which are connected in parallel are of equal ohmic value. This formula states that when parallel resistors are of the same ohmic value, the equivalent resistance is found by dividing the ohmic value of one of the resistors by the number of parallel resistors. Stated mathematically this becomes:

$$R_e = \frac{R}{N}$$

Where R_e is equal to the equivalent resistance, R is equal to the ohmic value of one resistor and N is the number of parallel resistors.

To illustrate the use of this formula refer again to Figure 4 which shows four 8 ohm resistors in parallel. Let us apply the formula to this circuit to determine the equivalent resistance of the four parallel resistors.

$$R_e = \frac{R}{N}$$

$$R_e = \frac{8}{4}$$

$$R_e = 2 \text{ ohms}$$

It will be recalled that the findings of the total current method which were performed previously also indicated that the equivalent resistance of the four 8 ohm resistors in parallel was 2 ohms.

Apply this formula to the parallel network of Figure 6 to determine the equivalent resistance and see if your computed equivalent resistance agrees with that of the equivalent circuit of Figure 6(B).

Figure 8 shows a parallel circuit with five 100,000 ohm resistors connected to a 100 volt source. The equivalent resistance of these resistors is 20,000 ohms as indicated by the following calculations:

$$R_e = \frac{R}{N}$$

$$R_e = \frac{100,000}{5}$$

$$R_e = 20,000 \text{ ohms}$$

To check these calculations apply the total current method of determining the equivalent resistance of the circuit of Figure 8. Do these calculations also indicate that the equivalent resistance of the parallel network is 20,000 ohms?

When the parallel circuit in question consists of only two resistors of unequal ohmic value another formula sometimes called the Product over Sum formula may be employed. This formula is:

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

Let us apply this formula to the circuit of Figure 7 to demonstrate its use.

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

$$R_e = \frac{4 \times 6}{4 + 6}$$

$$R_e = \frac{24}{10}$$

$$R_e = 2.4 \text{ ohms}$$

A check of the equivalent circuit of Figure 7(B) will illustrate that this is the same value of equivalent resistance as computed by the total current method.

Figure 9 illustrates a circuit such as may be encountered in a radio or television receiver. A 100,000 ohm and a 50,000 ohm resistor are connected in parallel across a 100 volt source. We wish to determine the equivalent resistance of these two resistors in parallel, or in other words, we wish to determine the amount of opposition offered by this parallel combination. Before working the problem there are at least two things which can be determined by inspection. In the first place we know that since the two resistors are in parallel the same voltage is applied across each, which is in this case 100 volts. We also know from the previous discussion the total opposition offered by the two parallel resistors is less than the smallest resistor and will, therefore, be less than 50,000 ohms. Let us apply the formula to determine just how much less than 50,000 ohms this value will be.

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

$$R_e = \frac{100{,}000 \times 50{,}000}{100{,}000 + 50{,}000}$$

$$R_e = \frac{5{,}000{,}000{,}000}{150{,}000}$$

$$R_e = 33{,}333 \text{ ohms}$$

The foregoing calculations require the use of a large number of zeros and the possibility of error from this source is present. For this reason it is advisable to apply powers of ten to this problem as follows:

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

$$R_e = \frac{100 \times 10^3 \times 50 \times 10^3}{100 \times 10^3 + 50 \times 10^3}$$

$$R_e = \frac{5,000 \times 10^6}{150 \times 10^3}$$

$$R_e = 33.3 \times 10^3$$

$$R_e = 33,300 \text{ ohms}$$

It can be seen that this answer is practically the same as that obtained previously, the slight difference being due to the fact that the division of 5,000 by 150 is only carried to three significant figures. This answer is sufficiently accurate for all radio and television work.

It should be mentioned that the <u>Product</u> <u>over</u> <u>Sum</u> formula may be used to determine the equivalent resistance of two parallel resistors, even if they are of equal ohmic value. When the resistors are of equal size, however, it is a simpler process to determine the equivalent resistance by means of the formula stated previously for use with parallel resistors of equal value. To demonstrate this fact determine the equivalent resistance of the parallel circuit of Figure 6(A) by the Product over Sum method.

There is a formula which can be used to determine the equivalent resistance of any number of parallel resistors. This formula is often called the reciprocal formula and is as follows:

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \text{ etc.}$$

To demonstrate the use of this formula let us find the equivalent resistance of the circuit shown in Figure 10.

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

$$\frac{1}{R_e} = \frac{1}{12} + \frac{1}{6} + \frac{1}{4}$$

(NOTE: 12 is the lowest common denominator.)

$$\frac{1}{R_e} = \frac{1 + 2 + 3}{12}$$

$$\frac{1}{R_e} = \frac{6}{12}$$

$$\frac{R_e}{1} = \frac{12}{6}$$

$$R_e = \frac{12}{6}$$

$$R_e = 2 \text{ ohms}$$

The circuit of Figure 10 is identical with the circuit of Figure 3(B) and a check of the computations concerning that problem will indicate that the equivalent resistance was found to be 2 ohms by the total current method. This should demonstrate that the new formula is valid.

To further demonstrate the use of the reciprocal formula let us find equivalent resistance of the parallel circuit shown in Figure 11.

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

$$\frac{1}{R_e} = \frac{1}{10,000} + \frac{1}{20,000} + \frac{1}{100,000}$$

$$\frac{1}{R_e} = \frac{10 + 5 + 1}{100,000}$$

(NOTE: 100,000 is the lowest common denominator.)

$$\frac{1}{R_e} = \frac{16}{100,000}$$

$$\frac{R_e}{1} = \frac{100,000}{16}$$

$$R_e = \frac{100,000}{16}$$

$$R_e = 6,250 \text{ ohms}$$

Once again note that the equivalent resistance of the parallel network is smaller than the smallest resistor in the network. To verify the fact that the above solution is correct the Associate is advised to work the problem represented by the circuit of Figure 11 by means of the total current method to check the results shown.

It will be noted in finding the equivalent resistance of parallel resistors by means of the reciprocal formula that it is necessary to use the lowest common denominator in the solution. Since it is sometimes a rather involved process to do this, particularly if the values of resistance are uneven amounts such as 27,000 ohms or 330,000 ohms, some prefer to work this type of problem using the Product over Sum formula. This formula can be used for only two branches at a time but can be used for finding the equivalent resistance of more than two branches by solving first to find the equivalent resistance of two of the parallel branches and then using this equivalent resistance and the resistance of the third branch, to find the equivalent resistance of the entire circuit. This is illustrated in Figure 12.

Let us first find the equivalent resistance of the 12 ohm resistor and the 6 ohm resistor in the circuit of Figure 12. To do this we substitute these values of resistance in the Product over Sum formula.

$$R_e = \frac{12 \times 6}{12 + 6}$$

$$R_e = \frac{72}{18}$$

$$R_e = 4 \text{ ohms}$$

By means of this calculation we have found the equivalent resistance of the 12 ohm and the 6 ohm resistors to be 4 ohms. In Figure 12(B) the circuit of Figure 12(A) has been redrawn and a 4 ohm equivalent resistance has been substituted for the 12 ohm and 6 ohm resistors. Substituting the values of Figure 12(B) in the equation we solve for the equivalent resistance of the entire network.

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

$$R_e = \frac{4 \times 4}{4 + 4}$$

$$R_e = \frac{16}{8}$$

$$R_e = 2 \text{ ohms}$$

While this method is in two steps and is a little longer, it eliminates the need for using a lowest common denominator which, as mentioned previously, can be very troublesome when involving odd values of resistors.

The Associate is advised to use the Product over Sum formula to solve the problem presented by Figure 11. First use this formula to determine the equivalent resistance of the 10,000 ohm and the 20,000 ohm resistor in parallel. Substitute the equivalent resistance of these two branches in the circuit and again apply the formula using this equivalent resistance and the 100,000 ohm resistor. Your answer should be practically the same as that computed previously for the equivalent resistance of this network. (6250 ohms)

Summary

The parallel circuit is a circuit in which two or more paths are provided for the current. The parallel paths are sometimes referred to as the branches or arms of the parallel circuit.

There are two important facts which should be borne in mind concerning parallel circuits. One of these is the fact that the voltage applied to all branches of a parallel circuit is equal since it is actually the same voltage applied to the various branches. The second important fact concerning parallel circuits is: the equivalent resistance of a parallel network is always less than the smallest resistance in the network. This should be an apparent fact to the Associate when he recalls that resistance is the opposition offered to current flow and, if two or more paths are provided, the opposition is naturally less than that offered by any of the paths.

The ohmic value of the equivalent resistance of parallel resistors can be computed in a number of manners. One method is to determine the amount of current flowing through each branch of the circuit by Ohm's Law and then to add the branch currents to find the total current flowing in the circuit. This total current and the applied voltage may then be used to determine the equivalent resistance by means of Ohm's Law. There are, likewise, several formulas which may be employed to determine the equivalent resistance of parallel circuits. The formula which is used is determined largely by the choice of the Associate and the type of circuit arrangement employed. If the parallel branches are of equal ohmic resistance the following formula may most conveniently be employed.

$$R_e = \frac{R}{N}$$

If the parallel circuit consists of two branches the following formula may be used very conveniently.

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

The equivalent resistance of any parallel circuit can be solved by using the following formula:

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \text{ etc.}$$

To become fully acquainted with the solution of circuits containing parallel resistors the Associate is advised to draw a number of such circuits and solve the circuits for the various unknown factors. To aid in this exercise three circuits are presented in Figure 13. Work each of these circuits carefully before checking your results against the proper solutions indicated at the end of the assignment.

Answers To Exercise Problems

Problems Presented By Circuits Of Figure 5

Problem 5. Total Current

The current drawn from the battery in this case will be 17 milliamperes or .017 ampere as determined in the following manner. The current from the battery is equal to the sum of the currents passed through the individual resistors or:

.010
.005
.002
.017 ampere or 17 milliamperes

Problem 5. Equivalent Resistance

The total current has been computed to be 17 milliamperes or .017 ampere. To find the equivalent resistance Ohm's Law formula should be applied as follows:

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

$$R = \frac{100}{.017}$$

$$R = 5,882 \text{ ohms}$$

Notice once again that the equivalent resistance of the parallel circuit- in this case the circuit of Figure 5- is smaller than the resistance of any branch of that circuit.

Problems Presented By Circuits Of Figure 13

Problem 13(A).

The equivalent resistance of R_1, R_2 and R_3 is 1,000 ohms as determined by the following calculations.

$$R_e = \frac{R}{N}$$

$$R_e = \frac{3000}{3}$$

$$R_e = 1000 \text{ ohms}$$

The current flowing through each resistor can be determined by Ohm's Law since the applied voltage is 100 volts.

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

$$I = \frac{100}{3000}$$

$$I = .0333 \text{ amp or } 33.3 \text{ ma}$$

The total current drawn from the battery can be determined in two ways. In the first place it has been established that the equivalent resistance of the parallel network is 1,000 ohms. This value can be used to determine the total current.

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

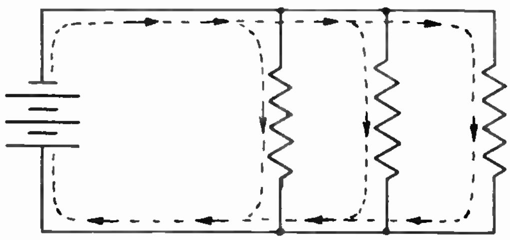
$$I = \frac{100}{1000}$$

I = .1 amp or 100 ma

The total current can also be found to be 100 milliamperes by adding the three individual currents which, as computed previously, are 33.3 milliamperes each.

.0333
.0333
.0333
.0999 ampere or 100 ma

The current paths are indicated in the accompanying diagram.



Problem 13(B).

The equivalent resistance of R_1 and R_2 can be most easily determined in this case by applying the Product over Sum formula.

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

$$R_e = \frac{27,000 \times 33,000}{27,000 + 33,000}$$

$$R_e = \frac{891,000,000}{60,000}$$

R_e = 14,850 ohms

The total current flowing in the circuit can be computed by applying Ohm's Law using the battery voltage as indicated, and the equivalent resistance which has just been computed.

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

$$I = \frac{50}{14,850}$$

I = .0034 ampere or 3.4 ma

Problem 13(C).

The reciprocal formula is applied to determine the equivalent resistance of the three resistors as follows:

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

$$\frac{1}{R_e} = \frac{1}{2} + \frac{1}{5} + \frac{1}{10}$$

$$\frac{1}{R_e} = \frac{5 + 2 + 1}{10}$$

$$\frac{1}{R_e} = \frac{8}{10}$$

$$R_e = \frac{10}{8}$$

R_e = 1.25 ohms

The current flowing through each resistor can be determined by the application of Ohm's Law to the three individual resistors since the resistance of each is known and the applied voltage is 10 volts in each case.

2 ohm resistor

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

$$I = \frac{10}{2}$$

I = 5 amps

5 ohm resistor

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

$$I = \frac{10}{5}$$

I = 2 amps

10 ohm resistor

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

$$I = \frac{10}{10}$$

I = 1 amp

The total current can be computed by applying Ohm's Law using the battery voltage indicated and the equivalent resistance which has just been computed.

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

$$I = \frac{10}{1.25}$$

I = 8 amps

Test Questions

Be sure to number your Answer Sheet Assignment 8B.
Place your Name and Associate Number on every Answer Sheet.
Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. Is the electromotive force applied to a circuit measured in; (a) amperes, (b) volts, or (c) ohms?

2. (A) If the value of a resistor in a radio diagram is indicated as being 13K, what is the value of that resistor in ohms?

   (B) If a resistor in a schematic diagram is labeled 2 megohms, how many ohms of resistance are there in the resistor?

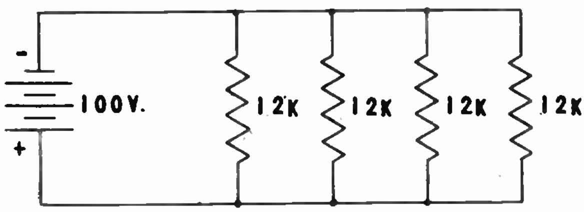
3. Is the equivalent resistance of a parallel network, (a) equal to the value of the smallest resistor forming the network, (b) equal to the value of the largest resistance forming the network, (c) larger than the largest resistor in the network, (d) smaller than the smallest resistance forming the network?

4. What general statement can be made concerning the value of voltage applied to the various resistors in a parallel arrangement?

5. If a parallel network consists of three resistors and the current flowing through the first resistor is 1 ampere, that through the second resistor is 2 amperes and that through the third resistor is 3 amperes, what is the total current drawn from the battery?

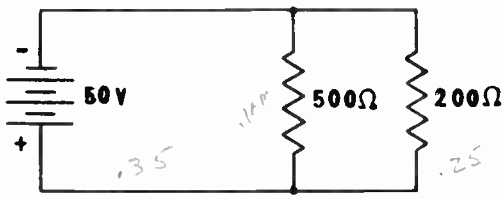
6. On your Answer Sheet redraw the circuit of Figure 6(A). Indicate by means of a dotted line with arrowhead the direction of the current flow through each resistor in the circuit.

7. In the accompanying diagram what is the equivalent resistance of the four resistors?



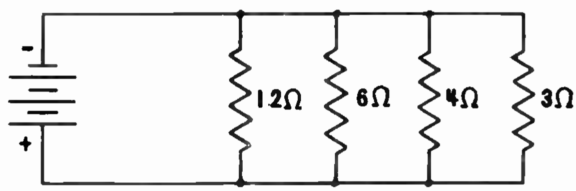
8. In the accompanying diagram find the equivalent resistance of the two resistors by application of the Product over Sum formula, show your work.

Re = 142.8
143.



9. In the circuit of Question 8; (a) what is the current through the 500 ohm resistor; (b) what is the total current drawn from the battery?

10. In the accompanying diagram find the equivalent resistance of the four resistors. Show your work. 1.2



Re 1.2

PARALLEL CIRCUIT WITH FIVE EQUAL RESISTORS

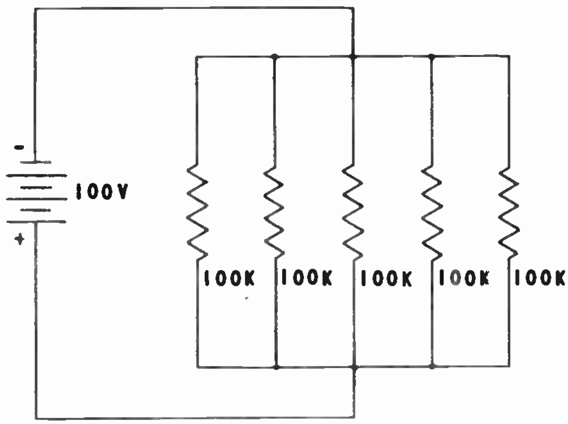


FIGURE 8

PARALLEL CIRCUIT WITH TWO UNEQUAL RESISTORS

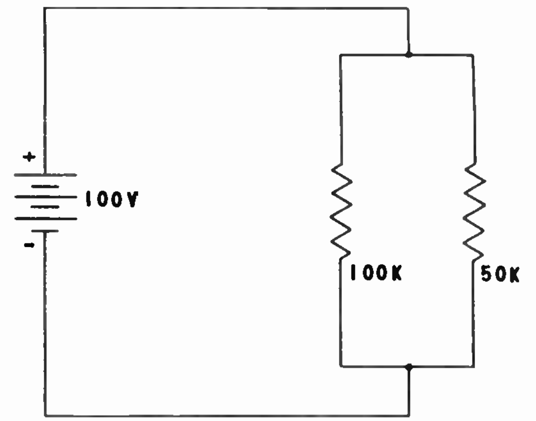


FIGURE 9

PARALLEL CIRCUIT WITH THREE RESISTORS

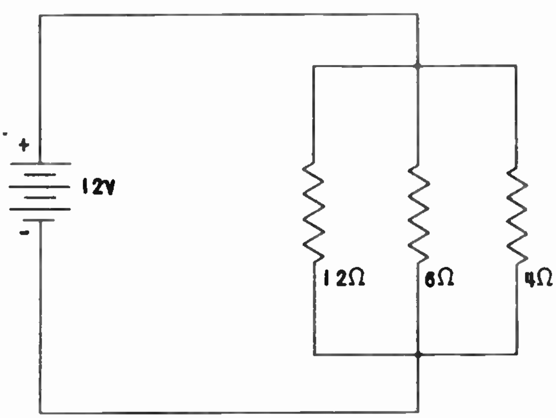


FIGURE 10

PARALLEL CIRCUIT WITH THREE RESISTORS

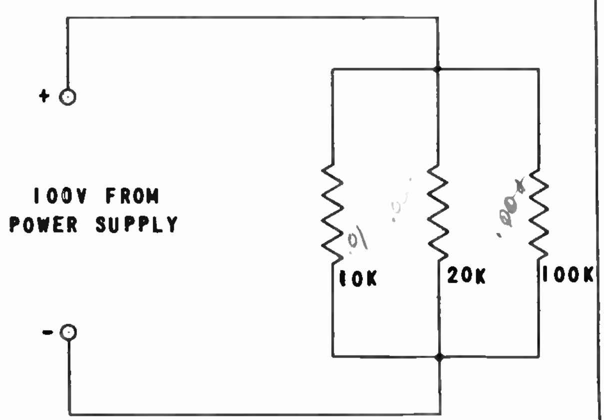
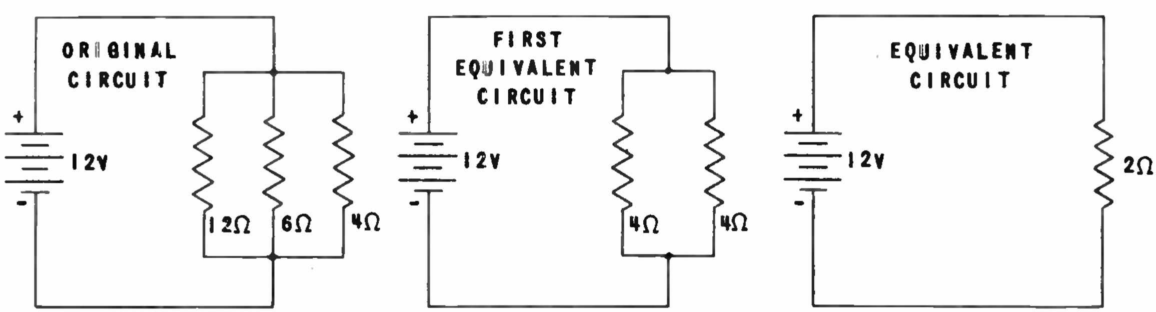


FIGURE 11

PARALLEL CIRCUIT WITH THREE RESISTORS



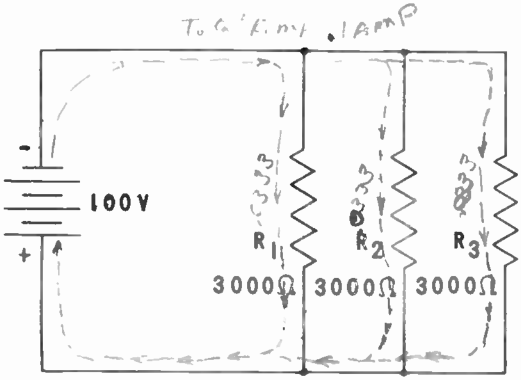
(A) (B) (C)

$$R_e = \frac{12 \times 6}{12 + 6} = \frac{72}{18} = 4\Omega$$

$$R_e = \frac{4 \times 4}{4 + 4} = \frac{16}{8} = 2\Omega$$

FIGURE 12

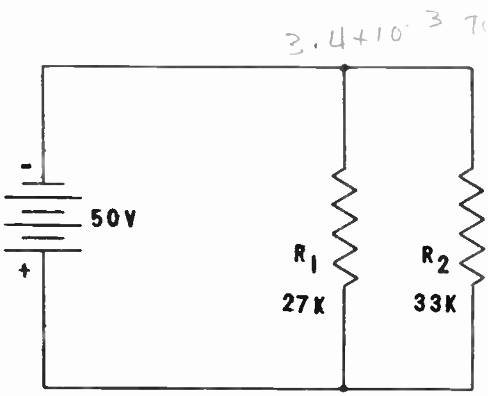
PARALLEL CIRCUIT PROBLEMS



FIND:
EQUIVALENT RESISTANCE OF R_1, R_2, R_3.
CURRENT FLOWING THROUGH EACH RESISTOR.
TOTAL CURRENT DRAWN FROM BATTERY.

SHOW:
CURRENT PATHS BY MEANS OF DOTTED LINE.

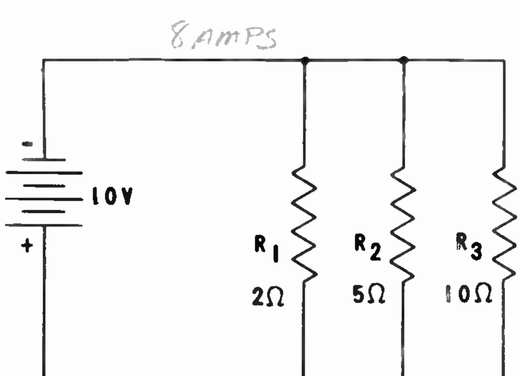
FIGURE 13-A



Re = 14.85+10^3

FIND:
EQUIVALENT RESISTANCE OF R_1 AND R_2.
TOTAL CURRENT FLOWING IN CIRCUIT.

FIGURE 13-B

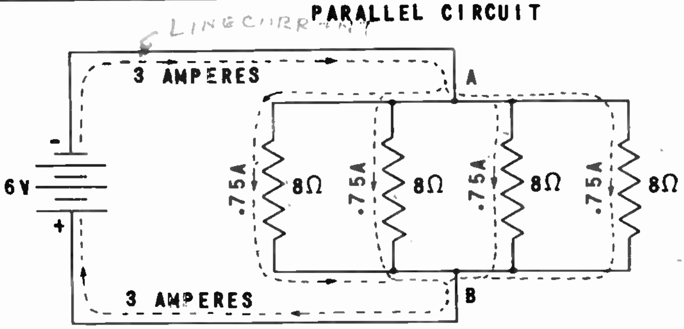


R	E	I
2	10	5
5	10	2
10	10	1

FIND: = 1.25
EQUIVALENT RESISTANCE BY RECIPROCAL FORMULA.
CURRENT THROUGH EACH RESISTOR.
TOTAL CURRENT.

FIGURE 13-C

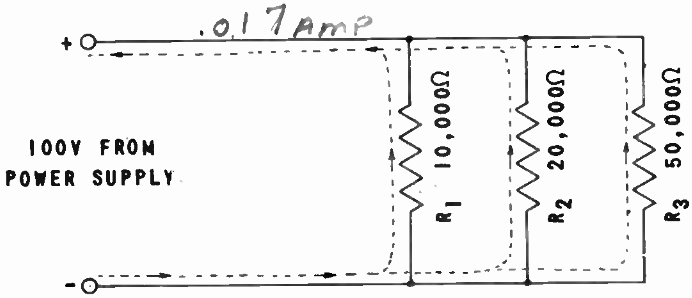
PARALLEL CIRCUIT



R	E	I
8	6	.75
8	6	.75
8	6	.75
8	6	.75

FIGURE 4

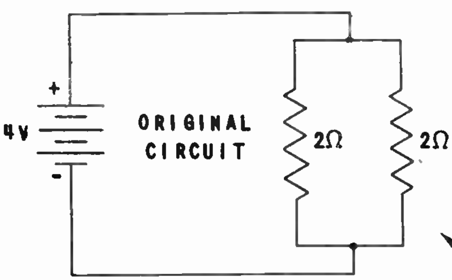
PARALLEL CIRCUIT



R	E	I
10K	100	.01
20K	100	.005
50K	100	.002

FIGURE 5

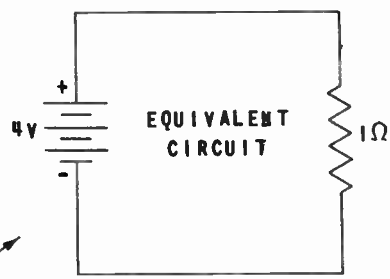
PARALLEL CIRCUIT



(A)

R	E	I
2	4	2
2	4	2

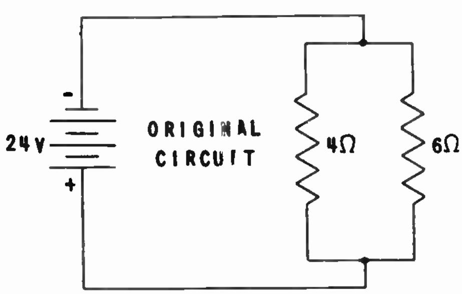
TOTAL CURRENT IS THE SAME (4 AMP.) FOR BOTH CIRCUITS



(B)

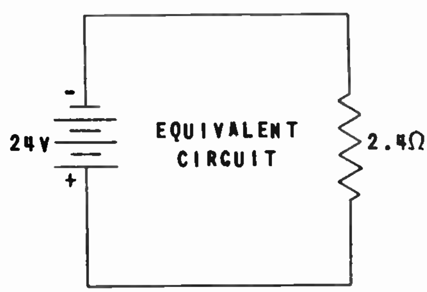
FIGURE 6

PARALLEL CIRCUIT



(A)

R	E	I
4	24	6
6	24	4



(B)

FIGURE 7

CIRCUIT ARRANGEMENTS

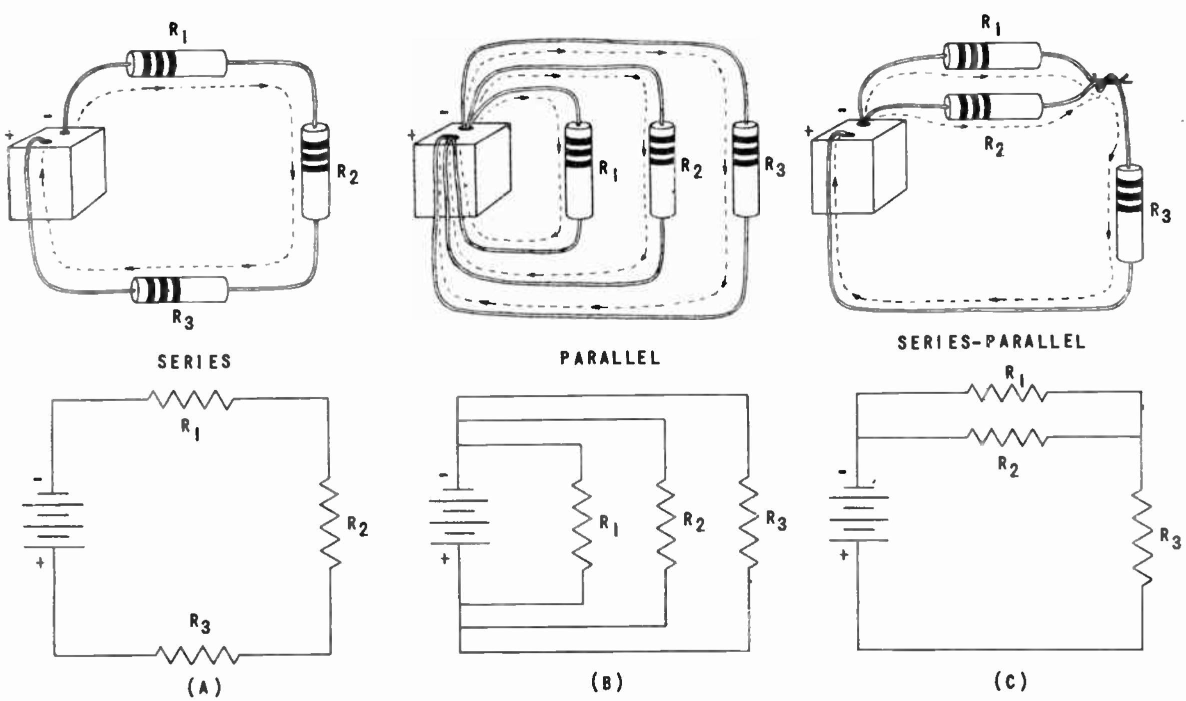


FIGURE 1

THREE SIMPLE SERIES CIRCUITS

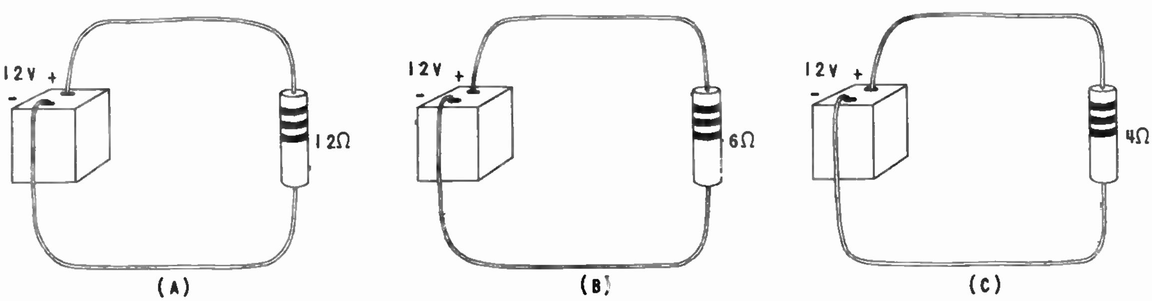
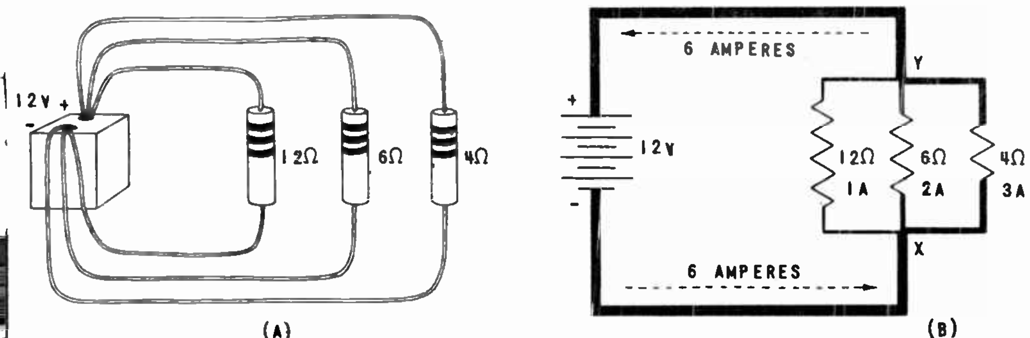


FIGURE 2

PARALLEL CIRCUIT



R	E	I
12	12	1
6	12	2
4	12	3

FIGURE 3

Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

CELLS AND BATTERIES—POWER AND ENERGY

ASSIGNMENT 9

ASSIGNMENT 9

CELLS AND BATTERIES - POWER AND ENERGY

In circuits and drawings we have been dealing with in the preceding assignments, we have shown batteries and cells as the source of the emf, but no explanation of the operation of the batteries or cells has been given.

In this assignment we shall discuss a number of different types of cells and batteries and shall compare the characteristics of the various types.

The purpose of a cell, or battery, is to produce an emf or voltage. The emf so produced will cause electrons to flow through a closed circuit. Cells produce an emf by changing chemical energy into electrical energy.

It will be both interesting and useful to know something of the operation of batteries. Most modern home radio receivers are operated from a 110 volt alternating current receptacle, but portable sets and much specialized electronic equipment operate from batteries. Typical types of electronic and radio equipment operating from batteries are: Auto radios, two-way radio systems in police cars and taxicabs, receivers and transmitters on ships and in aircraft, and portable radio equipment of the armed forces, portable receivers for entertainment, radiation meters, traffic radar devices, and many others. Thus, it is necessary for a qualified electronics technician to understand the operating principles of cells and batteries.

The Voltaic Cell

In the 18th century, an Italian physician (Galvani) made a very crude form of electric cell. He discovered that two pieces of different metals touching the nerves of the leg of a freshly-skinned dead frog would cause muscular contractions, or jerks, provided the other ends of the metal were in contact. He thought this electrical effect was caused by the frog.

Another Italian (Volta) proved that it was possible to produce electrical effects apart from any living creature. We take this for granted now, but it was a very important discovery at the time. Volta built a simple electric cell consisting of two rods of different materials in a weak solution of sulphuric acid. The two rods he used were carbon and zinc. Such a cell is illustrated in Figure 1(a). The rods or plates used in cells are called the *plates* or *poles* of the cell, and the solution used is called the *electrolyte*. (pronounced e-lec'-tro-lite).

When a copper wire was connected between the two rods, outside the cell, as shown in Figure 1(a), the wire became warm due to the flow of electrons through the wire. If we were to perform the experiment, we could place a voltmeter across the two terminals of the cell and measure the voltage produced. This is shown in Figure 1(b). If we preferred, we could place an ammeter in series with the copper wire connecting the terminals of the cell, in order to measure the flow of current in the wire. The cell we have just discussed is called a "Voltaic Cell". The zinc rod is the *negative* plate of the cell, and the carbon rod is the *positive* plate.

In this cell, voltage is produced due to chemical action within the cell. The weak solution of sulphuric acid enters into a chemical reaction with the zinc plate. This action would go on at a slow rate, if there were no complete circuit outside the cell, from the zinc to the carbon plate. When a complete circuit is established outside the cell, such as the copper wire between the two terminals in Figure 1(a), the chemical action increases, and the zinc plate will be "eaten" by the acid at a much faster rate. After this type of cell has been in operation for some time, the zinc plate will be "eaten away" by the acid, and will have to be replaced. Also, the acid solution will have to be replaced, since it has changed chemical composition and is no longer a weak solution of pure acid, but contains part of the zinc from the negative plate.

While this type of cell is not used in any present day radio installation, there are several actions which occur in it that also occur in modern cells, so we will discuss the action in this cell.

Let us trace the current path in the circuit of Figure 1(a). The current flows from the negative terminal of the cell, through the external circuit to the positive terminal of the cell, and *through the cell from the positive plate to the negative plate.* This current flow from the positive to negative pole *inside* the cell is actually carried out by the chemical action of the cell. There is some opposition offered by the electrolyte in conducting the current *inside* the cell, and this resistance is called the *internal resistance of the cell.* It is advantageous to have as low an internal resistance in a cell as possible.

If a Voltaic Cell is operated for any considerable length of time, bubbles of hydrogen gas collect on the carbon rod. This is illustrated in Figure 1(b). These hydrogen bubbles are produced by the chemical action taking place in the cell. Hydrogen is *not* a conductor of electricity, so when a sheath of hydrogen gas forms around the carbon plate, this plate becomes insulated from the electrolyte. More opposition is offered to the flow of current *through* the battery, or to state it another way, the *internal resistance* of the cell is increased. The result of increasing the internal resistance of a cell is that the output voltage will become lower. In Figure 1(b), the voltage output of the cell, as indicated by the voltmeter, would gradually decrease as the hydrogen bubbles form on the carbon plate. *The formation of hydrogen bubbles on the positive plate is called Polarization.*

Polarization is undesirable, since it increases internal resistance of the cell, and must be minimized if a cell is to be operated for a considerable length of time. It can be eliminated by adding a *depolarizer* to the cell. This depolarizer is a chemical which will not interfere with the chemical action taking place in the cell, but which will combine with the hydrogen bubbles and produce water. This removes the insulating sheath of hydrogen from the positive pole of the cell, and thereby reduces the internal resistance.

Another undesirable action which takes place in a cell is called *Local Action,* and results from impurities in the zinc plate. Zinc is one of the most difficult of metals to obtain in a *pure* state. Carbon is used in the process of purifying zinc, and some of this carbon remains in the form of tiny particles in the zinc plate. These small particles of carbon, the electrolyte, and the zinc pole set up small cells on the surface of the zinc plate. This is shown in Figure 1(a). The result of having these tiny cells on the surface of the zinc plate is that the zinc plate will be "eaten away" much more rapidly at these spots than on the remainder of the plate. This will require that the zinc plate and the electrolyte be replaced sooner than they would have if the zinc had been pure. No cheap method has been developed to eliminate local action.

A cell is said to be charged when the chemicals in it are in such a state that the cell is able to deliver its rated voltage and current to the external circuit.

There are two general types of cells. These are the *primary cell* and the *secondary cell*. The Voltaic Cell which we have discussed is one of the many primary cells. *A primary cell is a cell which can not be recharged when it is once discharged.* When a Voltaic Cell is discharged it must be rebuilt. A *secondary cell may be recharged when it is discharged.* We shall discuss some secondary cells and methods of charging these later in this assignment.

When an external circuit is connected to a cell, the cell is said to be *discharging*. A cell is completely *discharged* when it produces no voltage across the terminals.

The Dry Cell

A form of primary cell which is used very widely is the Dry Cell. The name Dry Cell is somewhat misleading because the cell is not dry, the chemicals being in the form of moist paste. Figure 2 shows the construction of a dry cell.

The negative plate of a dry cell is a zinc cylinder which forms the walls and bottom of the cell. The positive plate is a carbon rod placed in the center of the cylinder. The space between the carbon rod and the zinc container is filled with a paste of ammonium chloride, manganese dioxide, and powdered graphite. The top is covered with pitch or wax to prevent the loss of water by evaporation. A pin-hole in the pitch or wax permits the gas, which results from chemical action in the cell, to escape.

The ammonium chloride is the chemical which acts upon the zinc to supply the chemical energy which is converted into electrical energy. The manganese dioxide acts as the *depolarizer* to remove gas bubbles from the positive pole. The graphite is to reduce the *internal* resistance.

The emf of a new dry cell is about 1.5 volts. As the cell is discharged the output voltage will gradually decrease. In this cell the zinc is "eaten away" by the chemical action, and holes will usually be eaten through the zinc cylinder before the cell is completely discharged. Also the internal resistance of the cell increases greatly when the cell is partially discharged, due to the drying out of the paste electrolyte.

Dry cells are made in several sizes. The smallest practical cell is the "pen-lite" cell, which is about $\frac{1}{2}$ inch in diameter and about 2 inches long. Another dry cell is the flashlight cell which is $1\frac{1}{4}$ inches in diameter and $2\frac{1}{2}$ inches long. The largest dry cell in use today is the #6 cell which is $2\frac{1}{2}$ inches in diameter and 6 inches long. Each of these cells has an emf of 1.5 volts. The larger the cell, the greater the current it can deliver.

You may be wondering what the difference is between a cell and a battery. A battery is merely a group of cells connected together and usually placed in the same container. The cells may be connected in series, in parallel, or in series-parallel.

A type of battery which is used quite often in portable electronic equipment is the 45 volt "B" battery. The internal construction of such a battery is shown in Figure 3. In this battery, thirty small dry cells are connected in series. When the cells are connected in series, their voltages will add, so the full output voltage of this battery is 30 times 1.5 or 45 volts. On most of these batteries, there is a $22\frac{1}{2}$ volt tap brought out to a terminal on the outside of the battery. This is shown in Figure 3. Notice how the individual cells are connected together to form a battery. The positive terminal of the battery is connected to the positive pole of one of the cells. The negative pole of this cell is connected to the positive pole of the next cell. This continues for the entire thirty cells, and the negative pole of the last cell connects to the negative terminal of the battery. Check to see if you agree that the $22\frac{1}{2}$ volt tap is actually $22\frac{1}{2}$ volts more positive than the negative terminal of the battery.

Since the individual cells used in the 45 volt batteries are small, the maximum current that such a battery can provide is small. Twenty to 40 milliamperes is considered a reasonable current drain for these batteries. The large #6 dry cells can supply as much as 500 milliamperes or $\frac{1}{2}$ ampere for a reasonable length of time.

We have seen how it is possible to connect a number of dry cells to get an increased voltage. Thirty $1\frac{1}{2}$ volt dry cells connected in *series* produced a total voltage of 45 volts.

The total current which can be safely drawn from the *series* arrangement is the safe current of one of the individual cells, since the total current flows through *each* of the cells. In the 45 volt battery, each of the cells can safely supply $1\frac{1}{2}$ volts at 40 ma., so the entire battery can supply 45 volts at 40 ma.

It is possible to increase the current which can be safely supplied by cells by connecting them in *parallel*. This is shown in Figure 4(a). Four $1\frac{1}{2}$ volt dry cells are connected in parallel. To do this, the negative terminals of all of the cells are connected together, and this is the negative terminal of the battery. The positive terminals of all of the cells are connected together and this is the positive terminal of the battery. The output voltage of the battery is equal to the output voltage of one of the cells, $1\frac{1}{2}$ volts, but the total current drawn from the battery can be equal to the sum of the individual allowable currents of the cells. For example, if the four cells are #6 dry cells, which can supply $1\frac{1}{2}$ volts at $\frac{1}{2}$ ampere, then the battery can supply $1\frac{1}{2}$ volts at 2 amperes. The reason for this is shown in schematic diagram Figure 4(b). Each cell is supplying its allowable current of $\frac{1}{2}$ ampere, and the current through the resistor is the sum of the currents from each of the four cells, or 2 amperes.

Figure 5 shows a series-parallel arrangement, which is used when the battery current and voltage will be greater than that for each cell. Let us look at the row of cells nearest the resistor. These four cells are connected in series since the positive of the first is connected to the negative of the second, etc. The total voltage of this row of cells is, therefore, 4 times $1\frac{1}{2}$ volts or 6 volts. If these are #6 dry cells, each may safely deliver $\frac{1}{2}$ ampere, so this row can deliver 6 volts at $\frac{1}{2}$ ampere. The other five rows of cells are identical with the row nearest the resistor. Each of these rows has 6 volts and can supply $\frac{1}{2}$ ampere. These *rows* are connected in parallel. The battery voltage will be 6 volts, and the total current which may be drawn from this battery is the sum of the current which may be supplied by the individual rows, or 6 times $\frac{1}{2}$ ampere or 3 amperes. Notice that the resistor in the diagram is called the *load*. This term is used very widely in radio work. The resistor or other circuit component (it could be a coil) which is connected to the source of emf is called the load. In this case, our battery supplies 6 volts at 3 amperes to the load.

To summarize the connection of cells, we could say if cells are connected in *series, more voltage* is available and if cells are connected in *parallel, more current* is available.

Dry cells are *primary cells*, and the zinc containers are "eaten" away during their discharge so that they can not be recharged. When the output voltage drops below a satisfactory level, dry cells and batteries made from dry cells, must be discarded, and new batteries installed. As dry cells discharge, the internal resistance increases, and when the output voltage has fallen about 1/5 of the original voltage, the internal resistance of the cells becomes so high that the operation of the cell is unsatisfactory. Thus, a 45 volt battery should be replaced when the output voltage drops to about 36 volts. 45 - (1/5 x 45) = 45 - 9 = 36.

On the outside of most dry cells and batteries will be found a notation, telling by what date the battery should be placed in operation. This is because these batteries have a definite *shelf life*. If they are stored for too long a time they will become unsatisfactory. This is due mainly to the *local action* which takes place within the cell.

Most portable radios operate from "packs" of dry cell batteries. These packs contain two or three dry cell batteries. *A typical pack may have one battery, which supplies 90 volts at about 30 ma., and a $1\frac{1}{2}$ volt battery which supplies 300 ma.*

The Air Cell

Another type of battery, which has proved quite popular in the rural communities for supplying filament voltages for battery operated radio receivers, is known as the *air cell battery*. It consists of *two air cells* assembled in a hard rubber container and permanently connected in series.

The negative pole of this cell is zinc, and the positive pole is carbon, as in the dry cell, but the carbon pole is in the form of a rod of *porous* carbon. The electrolyte is a solution of sodium hydroxide and water. This battery gets its name from the fact that air is the *depolarizer*. When this battery is operated, air is absorbed by the porous carbon rod, and combines with the gas bubbles. The output voltage of each of the cells of an air cell battery is 1.25 volts, and the output voltage of an air cell battery is 2.5 volts, since it contains two air cells connected in series. These batteries have a long life, and their output voltage remains practically constant over their useful life.

The air cell is a *primary cell* and cannot be recharged. It must be discarded when its useful life is over.

Lead - Acid Storage Cell

In the explanation on primary cells, we saw how electricity was produced by chemical action, and you will remember that the cells were made up with two plates and a chemical solution called the electrolyte.

When an electrical circuit is completed between the plates outside the cell, a chemical action "eats away" some of the parts, but it produces an emf which causes a current to flow in the circuit.

The lead-acid storage cell has two plates or sets of plates and an electrolyte, but it differs from the primary cell in that its plates are not eaten away during discharge, but are just changed to another chemical composition. After being discharged, this cell can be recharged by forcing an electric current through it in the opposite direction to the discharge current. This charging process changes the plates back to their original chemical composition, and the cell is ready to be used again. We shall deal with the charging process shortly, but let us examine the construction of the cell.

A typical storage battery is shown in Figure 6. This type of battery was used in automobiles for many years and consists of three lead-acid cells connected in series.

The positive plates of a lead-acid cell are composed of lead peroxide, and the negative plates are spongy lead. To secure more surface area, the plates of a lead-acid cell are actually several plates connected together. This may be seen in Figure 6. All of the positive plates of one cell are connected together, and all of the negative plates of one cell are connected together. These sets of positive and negative plates are sandwiched together, so that there is first a negative plate and then a positive plate, then a negative plate etc. The plates are held apart by pieces of insulating material called *separators*. Separators are made of rubber, glass rods, or corrigated wood. The electrolyte is a dilute or weak solution of sulphuric acid. When this cell is connected to a load and discharged, the chemical composition of both plates will change to lead sulphate, which is a chemical combination of *lead and sulphuric acid*. The electrolyte changes from sulphuric acid to water. *Neither* of the plates are "eaten away" by the acid. After this cell has been discharged, or partially discharged, it can be changed back to its original chemical composition by *forcing* current through the cell in the opposite direction to the discharge current. This is known as *charging* the cell, and is done by a *charger*.

When the cell has been charged, the positive plate is again lead peroxide, the negative plate is again spongy lead, and the electrolyte is a weak solution of sulphuric acid. Now we see why this type of battery is in such wide use. Its chemical action is reversable. Once it has been discharged, all that has to be done to recharge it is to connect it to a charger. This is much cheaper than replacing it with a new battery.

The voltage of a lead-acid cell is 2.1 volts. This voltage remains practically constant until the cell is almost completely discharged, at which time the voltage drops to zero. The amount of current which can be delivered by this cell gradually drops as the cell is discharged. Since the voltage is practically constant, when no current is being drawn, regardless of the state of charge, a voltmeter is of little value in checking a lead-acid cell.

A very simple method of checking the state of charge of a lead-acid cell is by checking the *specific gravity* of the electrolyte.

As you perhaps know, the same amount, or volume, of different liquids have different weights. For example, one gallon of sulphuric acid weighs more than one gallon of water, while one gallon of gasoline weighs less. We call this the specific gravity of the liquid, which means the ratio of its weight compared to the weight of an equal volume of water. As water is the most common fluid, we say sulphuric acid weighs about twice as much as water, or 1.835 times as much, to be exact. As we mix the two for the electrolyte, the specific gravity of the solution will be somewhere between 1 and 1.835.

In the explanation of the lead cell, you remember, it was stated that when the cell was charged, the electrolyte was acid, and when the cell was discharged the electrolyte was water. In practical work, however, we never reach the condition of absolute discharge and no matter what state of charge the cell may have, there is always both acid and water in the electrolyte. As the cell charges, the chemical action takes place, and the amount of acid increases, giving us a very handy method of testing the state of charge of the battery.

It can be seen that we could pour out the electrolyte, weigh it and compare its weight to an equal amount of water. This would give us the specific gravity of the electrolyte, but this method would be far from handy.

The handy way to check the specific gravity of the electrolyte is through the use of a hydrometer. The hydrometer is shown in a drawing in Figure 7. The hydrometer consists of a large glass tube that has a rubber bulb at the top, and a small rubber tube at the bottom. Inside the large glass tube is a little float, which is weighted at the lower end with shot and has a scale in the upper part of the tube. Since the float is made of glass, the scale may be placed on the inside of the small tube, and we can read it from the outside.

To use a hydrometer to measure the specific gravity of the electrolyte, the small rubber tube is placed in the electrolyte, and the bulb on top of the hydrometer is squeezed. When the rubber bulb is released, electrolyte will be drawn up into the large glass tube, and the float will float in the electrolyte. The more acid that is in the electrolyte, the heavier, or denser, it will be. The float will sink only as far as the density of the liquid will let it. The more dense the liquid, the less the float will sink in the liquid.

By properly marking the scale, we can read the specific gravity of the electrolyte directly from the scale. The point on the scale that comes level with the surface of the liquid shows the specific gravity.

The scale in the hydrometer used to check the specific gravity of the electrolyte in a lead-acid storage cell is marked off in graduations from 1300 to 1100. The number 1300 means a specific gravity of 1.3 and 1100 means 1.1, but as it is much easier to say eleven fifty or twelve hundred than one and fifteen hundredths, or one and two tenths, the decimal point is left out.

The range of this scale, 1.1 to 1.3 is much less than the 1 to 1.835 that we mentioned before, but it covers the ordinary working range of the cell. If the acid gets so strong that its specific gravity is over 1.3,it will injure the plates and separators. If it gets so weak that it is below 1.1, the chemical action is so slow that the cell is of no use. A specific gravity reading of 1300 is considered a full charge, and 1100 a complete discharge.

A battery should never be allowed to stand for a long period of time in a discharged condition, since it may be ruined. This is because the plates, which are lead sulphate when the cell is discharged, may become so hard that the charging process cannot be performed. When this has happened to a battery it is said to be *sulphated*.

The lead-acid battery is often called a storage battery. For years the storage batteries in cars consisted of three cells in series, as shown in Figure 6. (3 x 2.1V. per cell = 6.3V.) Since 1955 most car batteries contain 6 cells in series, producing 12.6 Volts.

The amount of electricity, or current, that a cell can produce is called its capacity. From the chemical actions just explained, it can be seen that the greater amount of active plate material we have, the more electrical energy the cell will be able to produce.

The capacity of a storage battery is measured by the amount of current in amperes multiplied by the time it is produced in hours. This makes the unit for measuring the capacity of a battery the Ampere-Hour.

However, this is not quite as simple as it sounds, for a cell that will deliver 10 amperes for 10 hours will not necessarily deliver 100 amperes for 1 hour. In general, the higher the current, or rate of discharge, the smaller the capacity will be. Since capacity is a variable factor, when the time of discharge is variable, the time for discharging is generally set at 8 hours. Thus, a 100 ampere-hour battery will deliver $12\frac{1}{2}$ amperes for 8 hours, and a 300 ampere-hour battery will deliver $37\frac{1}{2}$ amperes for 8 hours.

Edison Cell

Another secondary cell, or cell that can be charged, is the Edison Cell. This cell is not used in automobiles, because it is rather costly, but it is used in many commercial applications, since it will stand much abuse and has a very long life.

In this cell, the active materials are nickel peroxide for the positive plate and finely divided iron for the negative plate. The electrolyte is a 26 per cent solution of potassium hydroxide.

Like the lead-acid cell, the plates are assembled in groups, and plates are held apart by spacers. The container for these cells, or batteries, is usually made of nickel-plated steel.

The chemical reactions which take place in this cell are very complex and have not been explained to the satisfaction of all chemists. The cell has an average voltage of 1.2 volts, which is lower than other lead-acid types, but it is not injured by discharging to zero voltage, by standing idle, or by over charging. The specific gravity of the electrolyte does not change during the charging and discharging processes. The state of charge of this battery should be determined by measuring its output voltage while it is delivering its rated current. The voltage of a fully charged Edison cell is 1.37 volts.

Charging Batteries

To charge a battery it is only necessary to connect the battery to a source of emf higher than the battery voltage. Thus, to charge a 12.6 volt storage battery, it should be connected to a source of emf of about 16 volts. The proper way of connecting a charger to a battery is shown in Figure 8. Since the voltage of the charger is higher than the battery voltage, it will force current *through the battery* from the negative terminal to the positive terminal. This current flow *through the battery* is in the opposite direction to the discharge current which, you will recall, flows from the positive to the negative plates. The flow of current from the negative to the positive plates in the storage cell reverses its chemical process, restoring the battery to its original charged state.

Few precautions need be observed in charging an Edison Cell, since it is not affected by overcharging, too fast a charging rate, etc., but several precautions should be observed in charging a lead-acid battery.

As a lead-acid battery is charged, hydrogen gas bubbles up from the plates. Hydrogen is an explosive gas, so charging should be done in a well ventilated room.

The charging rate should be adjusted, by adjusting the charger voltage, so that only a small amount of bubbling occurs around the plates. The amount of bubbling is proportional to the amount of heat produced in the battery, since all chemical processes produce heat. If the charging rate is too high, too much heat will be produced in the battery, and the plates of the battery will warp and adjacent positive and negative plates are likely to touch together, ruining the battery. When a battery has reached a specific gravity of 1300, it should be disconnected from the charger, as overcharging a battery will cause the plate material to be washed away by the bubbling action of the electrolyte. Normally, a battery can be charged at a high rate when its charge is low, and the rate should be reduced as the battery approaches full charge. During charging, part of the water in the electrolyte will boil away. The level of the electrolyte should be brought up to slightly above the top of the plate by adding distilled water. Ordinary drinking water should not be added, since it contains a lot of chemicals.

Battery chargers may be motor driven generators, or they may be rectifier circuits which change the 110 volts a-c to the proper value of d-c voltage. In either case, provision is made for regulating the rate of charge.

Power and Energy

Let us examine a few fundamental concepts of physics and apply them to electrical circuits.

In physics, *force* is defined as that which produces, or tends to produce motion. Thus, if we push an automobile, we are applying force to the automobile. In an electrical circuit, the *force* is the electromotive force, and is, of course, measured in volts. The emf is the *force* in an electrical circuit which produces motion of the free electrons, or current flow. *Current* is the *motion* in an electrical circuit. In physics, force produces *motion* against an opposing *force*, such as friction or gravity. In an electrical circuit, the opposition is the *resistance* of the circuit.

Work is defined as the production of motion against an opposing force. *Power is a measure of the rate at which work is done.* Thus, if a certain amount of work is to be done, a large *powerful* motor would do the job more quickly than a small, less powerful motor. Power in electrical circuits is measured in *Watts.*

Another term which is used quite often in physics is *Energy*. *Energy is the ability to do work.* One of the fundamental laws of nature is that energy can be neither created or destroyed. The batteries which we just studied did not create electrical energy. They changed chemical energy to electrical energy. In resistors, electrical energy is changed to heat energy. In an electric motor, electrical energy is converted into the energy of mechanical motion.

Electrical energy is measured in watt-hours. Before dealing with this term, let us take up the *watt.*

To repeat: The *watt* is the unit of electrical *power.*

There are three formulas which are used in finding the electrical power in an electrical circuit, or component of a circuit.

These formulas are:

(a) $P = E \times I$

(b) $P = I^2 \times R$

(c) $P = \frac{E^2}{R}$

P equals power in watts.
E equals the emf in volts.
R equals the resistance in ohms.
I equals the current in amperes.

Formula (a) is used when we wish to know the power, with the voltage and the current known.

Let us apply this formula to the circuit shown in Figure 4(b) to find the amount of power being delivered by the battery. The voltage is $1\frac{1}{2}$ volts, and the total current is 2 amperes. Putting these values in the formula we have:

$P = E \times I$

$P = 1\frac{1}{2} \times 2$

$P = 3$ watts

The total power being delivered by the battery (3 watts), is being supplied to the resistor. Since this power represents electrical energy, it cannot be destroyed. You are probably wondering what happens to it. The answer is that it is given off by the resistor in the form of heat. Electronics men generally say that this power is dissipated by the resistor. When a resistor carries current, it becomes warm. This is due to the power being dissipated in the resistor.

Resistors are rated according to the amount of power they can dissipate without overheating. In the circuit shown in Figure 4(b), the resistor would have to be at least a 3 watt resistor. If a smaller wattage rating than 3 watts is used in this case, the resistor will over-heat and be ruined.

Let us find the amount of power being delivered by each cell. Each cell has $1\frac{1}{2}$ volts and is passing $\frac{1}{2}$ ampere of current.

$P = E \times I$

$P = 1\frac{1}{2} \times \frac{1}{2}$

$P = \frac{3}{2} \times \frac{1}{2}$

$P = \frac{3}{4}$ watt (This is the power being delivered by *each* cell.)

In Figure 5, we see a 6 volt battery passing 3 amperes through a resistor. To find the amount of power being dissipated by the resistor, we apply the same formula:

$P = E \times I$

$P = 6 \times 3$

$P = 18$ watts

This same formula may be used to find the amount of heat given off by the resistor in Figure 9.

$P = E \times I$

$P = 45 \times .001$ (Note: 1 ma. was changed to .001, since the equation calls for amperes.)

$P = .045$ watt

Formula (b) is used when the current and the resistance are known, and the amount of power is desired. We can apply this formula to find the power dissipated by the 6 ohm resistor in Figure 10.

$P = I^2 \times R$

$P = (2)^2 \times 6$

$P = 4 \times 6$

$P = 24$ watts

Using this same formula, we could find the power dissipated by the resistor in Figure 11.

$P = I^2 \times R$

$P = (.003)^2 \times 2000$ (Note: Current is changed from 3 ma. to .003 amps)

$P = (3 \times 10^{-3}) \times (3 \times 10^{-3}) \times 2 \times 10^3$

$P = 9 \times 2 \times 10^{-6} \times 10^3$

$P = 18 \times 10^{-3}$

$P = .018$ watt

Formula (c) is used when the voltage and resistance are known.

Figure 12 shows such a problem. Substituting our known values in the equation, we can find the power dissipated.

$P = E^2/R$

$$P = \frac{(20)^2}{200}$$

$$P = \frac{400}{200}$$

$P = 2$ watts

Figure 13 presents a similar problem.

$P = E^2/R$

$$P = \frac{(100)^2}{10^6}$$

$$P = \frac{10^2 \times 10^2}{10^6} = \frac{10^4}{10^6} = 10^4 \times 10^{-6}$$

$P = 10^{-2}$ watts or .01 watt.

In Figure 14, it is desired to know the necessary wattage rating of each resistor. To solve this problem, we are going to have to apply Ohm's Laws. First let us find the total resistance of the circuit. The two resistors are in series, so we will apply the series resistance formula:

$R_t = R_1 + R_2$

$R_t = 80,000 + 20,000$

$R_t = 100,000$ ohms. This is the total resistance of the two resistors.

Now to find the current flowing in the circuit, we use the Ohm's Law formula:

$I = E/R$

$$I = \frac{100}{100,000}$$

$$I = \frac{10^2}{10^5}$$

$I = 10^2 \times 10^{-5}$

$I = 10^{-3}$ or 1 ma.

The power dissipated by the 80 K ohm resistor can be found by the formula:

$P = I^2 \times R$

$P = (.001)^2 \times 80,000$

$P = 10^{-3} \times 10^{-3} \times 8 \times 10^{4}$

$P = 10^{-6} \times 8 \times 10^{4}$

$P = 8 \times 10^{-2}$

$P = .08$ watt.

The power dissipated by the 20,000 ohm resistor is:

$P = I^2 \times R$

$P = (.001)^2 \times 20{,}000$

$P = 10^{-3} \times 10^{-3} \times 2 \times 10^{4}$

$P = 2 \times 10^{-2}$

$P = .02$ watt

Figure 15 illustrates a typical radio circuit. The milliampere meter indicates that there is a current of 5 ma. flowing through the 100,000 ohm resistor. How much power will be dissipated by the resistor?

$P = I^2 \times R$

$P = (.005)^2 \times 100{,}000$

$P = 5 \times 10^{-3} \times 5 \times 10^{-3} \times 10^{5}$

$P = 25 \times 10^{-6} \times 10^{5}$

$P = 25 \times 10^{-1}$

$P = 2.5$ watts.

In Figure 16, we see a circuit consisting of a 100 volt battery and three parallel resistors. Let us find the power dissipated in each resistor.

These resistors are connected in parallel, therefore, they have the same voltage across them. There is an emf of 100 volts across each resistor. Since we know the voltage across each resistor, and the ohmic value of each resistor, we can use the formula $P = \frac{E^2}{R}$ to find the power delivered to each resistor.

To find the power dissipated by the 200 ohm resistor:

$P = E^2/R$

$$P = \frac{(100)^2}{200}$$

$$P = \frac{10^2 \times 10^2}{2 \times 10^2}$$

$$P = \frac{10^2 \times 10^2 \times 10^{-2}}{2}$$

$$P = \frac{10^2}{2}$$

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

$P = 50$ watts.

To find the power dissipated in the 10,000 ohm resistor:

$P = E^2/R$

$$P = \frac{(100)^2}{10,000}$$

$$P = \frac{10^2 \times 10^2}{10^4}$$

$$P = \frac{10^4}{10^4}$$

P = 1 watt.

To find the power dissipated in the 1 megohm resistor:

$$P = E^2/R$$

$$P = \frac{(100)^2}{10^6}$$

$$P = \frac{10^2 \times 10^2}{10^6}$$

$$P = \frac{10^4}{10^6}$$

$$P = 10^4 \times 10^{-6}$$

$$P = 10^{-2}$$

P = .01 watt.

Would you have suspected that there would be such a big difference in the power dissipated (or amount of heat generated) by the three resistors in Figure 16?

To check the arithmetic in the example, apply Ohm's Law and find the current flowing in each resistor. Then apply the power formula $P = I^2 \times R$ to find the power dissipated in each resistor.

Suppose an electric iron were drawing 11 amperes from a 110 volt source. How much power would be drawn from the source? We know the voltage and current. We will use the formula P = E x I.

P = E x I

P = 110 x 11

P = 1210 watts or 1.21 kilowatts.

Energy

As mentioned previously, watt-hour is the measure of electrical energy. One watt-hour of electrical energy is consumed when 1 watt of power continues in action for 1 hour. Similarly, 1000 watt-hours of energy is consumed when the power is 1000 watts and continues for 1 hour, or when 100 watts of power continues for 10 hours. We see that the amount of *energy depends on both power and time.*

If the iron in the preceding example were operated for one hour, then 1210 watt-hours of electrical energy has been supplied by the power company. The term kilowatt-hour is often used for large amounts of energy. 1210 watt-hours is equal to 1.21 kilowatt-hours, (abbreviated 1.21KWH). If this same iron were operated for 5 hours, 5 x 1.21 or 6.05 KWH of energy would have to be supplied to it.

The consumer of electrical energy pays for the amount of energy used by his apparatus. If your home is served by a public utility company, you will find a kilowatt-hour meter near the fuse-box. This meter is read regularly by the utility company, and you are billed for the amount of electrical energy, in KWH, which was supplied to your home.

Let us summarize the material covered in this assignment.

All cells convert chemical energy into electrical energy. There are two general classifications of cells, these are Primary cells and Secondary cells.

Primary cells *cannot* be charged.

Secondary cells *can* be charged.

Voltaic cells, Dry cells and Air cells are primary cells.

Lead-acid cells and Edison cells are secondary cells.

Batteries are groups of cells.

Cells are connected in series to obtain higher voltage.

Cells are connected in parallel to obtain higher current.

Formation of hydrogen bubbles on the positive plate of a cell is called polarization.

The chemical put in cells to minimize polarization is called the depolarizer.

Local action in a cell results from impurities in the zinc.

Internal resistance is the name given the opposition offered by the electrolyte of a cell in carrying the current *inside of the cell.*

Power is the rate of doing work.

Power is measured in watts.

There are three formulas for finding power:

$$P = E \times I, \qquad P = I^2 \times R, \qquad P = \frac{E^2}{R}$$

Energy is the ability to do work.

Energy is measured in watt-hours.

Energy can be neither created nor destroyed. It can be converted from one form to another. For example, from chemical energy to electrical energy, as in batteries, or from electrical to heat as in an electric stove.

In this assignment, we have learned a great deal about batteries. There are two other widely used sources of d-c voltage; the d-c generator, and the rectifier, which changes a-c into d-c. These will be studied in detail in future assignments.

Test Questions

Be sure to number your Answer Sheet Assignment 9.
Place your Name and Associate Number on *every* Answer Sheet.
Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. What is the difference between a primary cell and a secondary cell?
2. What is the difference between a cell and a battery?
3. If three dry cells were available and you desired a voltage of 4.5 volts, in what manner should the cells be connected?
4. The specific gravity of a lead-acid storage cell is 1300. Is this cell *fully charged, completely discharged, or partly discharged?*
5. Suppose you had a battery connected to a charger and noticed that there were *a great deal* of bubbles rising around the plates. What should you do?
6. If you were charging a battery and noticed that the level of the electrolyte was below the top of the plates, what should you do?
7. What is the unit of power? Watts
8. An electric iron draws 20 amperes of current from a 100 volt source. How much energy must be supplied by the utility company to operate this iron for 5 hours?
9. Energy cannot be destroyed. What happens to the energy which is supplied to a resistor carrying current?
10. Name three primary cells.

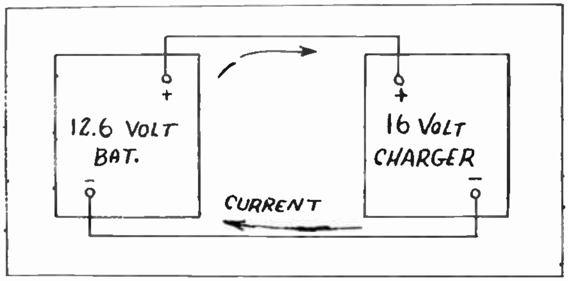


FIG. 8

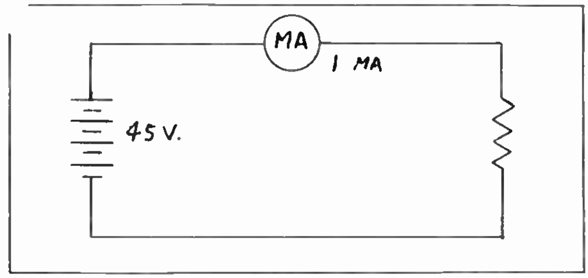


FIG. 9

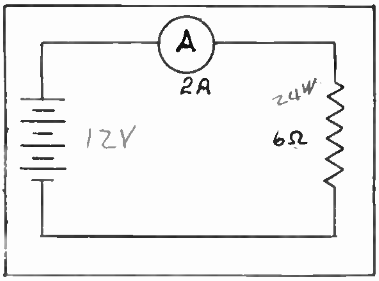


FIG. 10

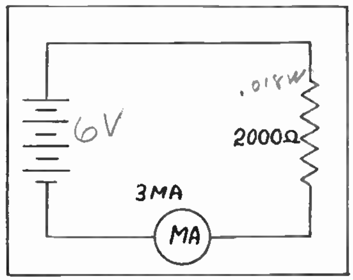


FIG. 11

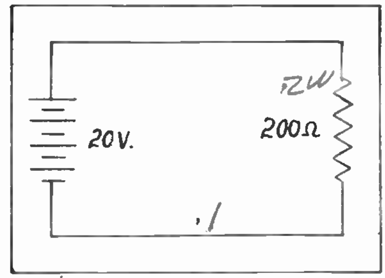


FIG. 12

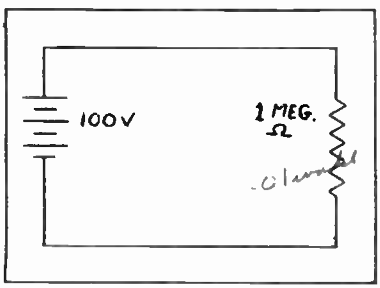


FIG. 13

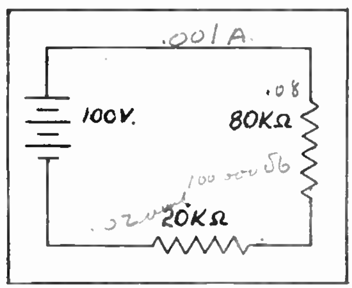


FIG. 14

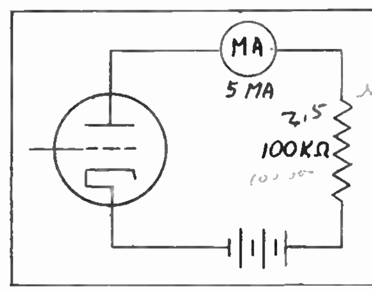


FIG. 15

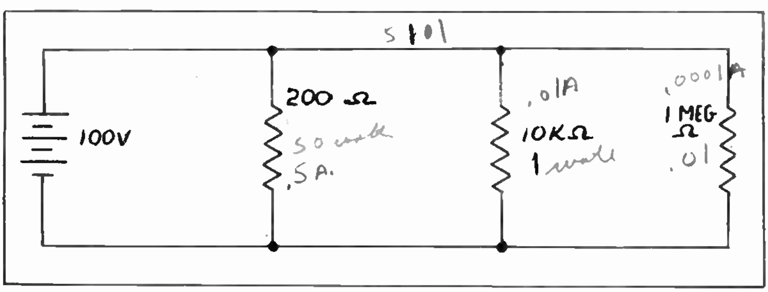


FIG. 16

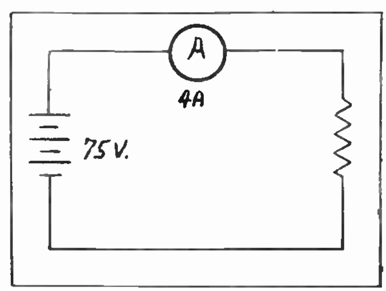


FIG. 17

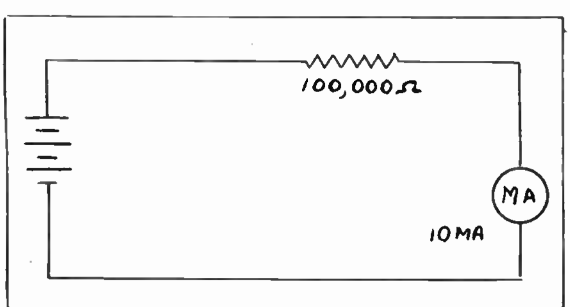


FIG. 18

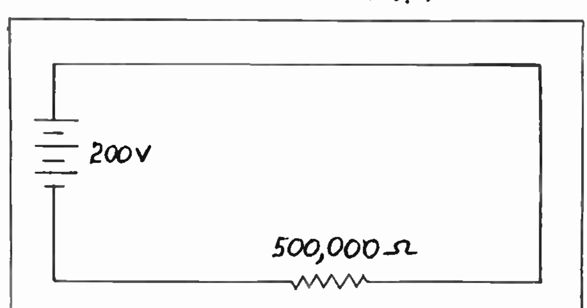


FIG. 19

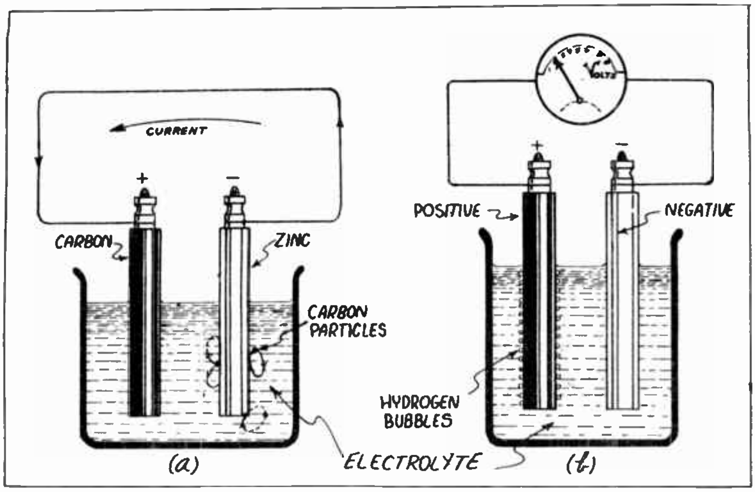


FIG. 1

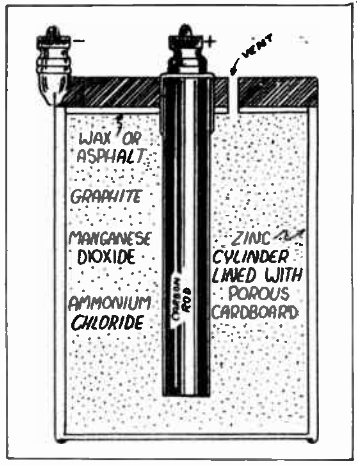


FIG. 2

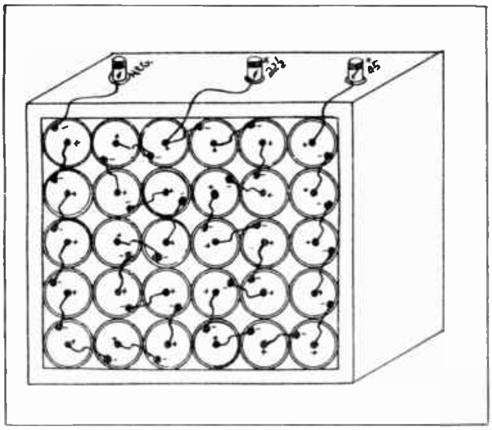


FIG. 3

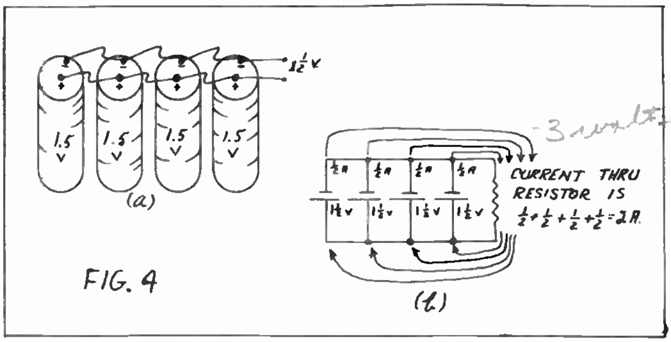


FIG. 4

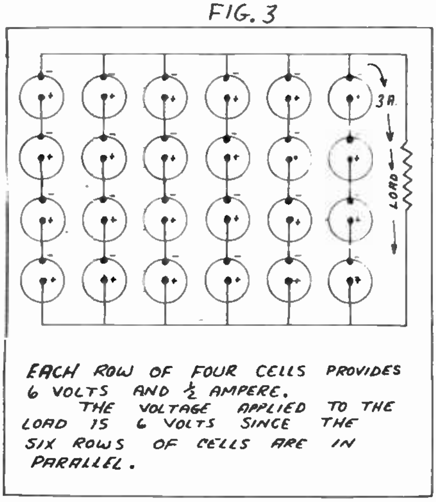


FIG. 5

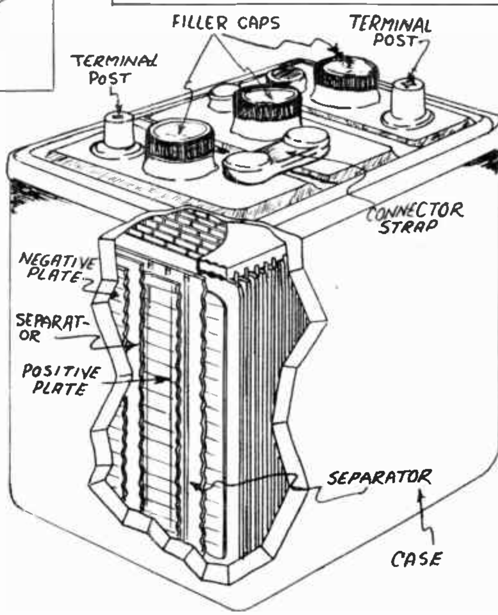


FIG. 6

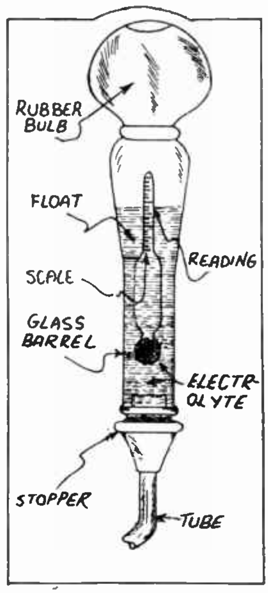


FIG. 7

Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

ELEMENTARY ALGEBRA FOR ELECTRONICS

ASSIGNMENT 10

ASSIGNMENT 10

ELEMENTARY ALGEBRA FOR ELECTRONICS

In the mathematics studied in the previous assignments, we have dealt with the solution of arithmetic problems. These are problems involving addition, substraction, multiplication and division of positive numbers. We have also studied roots and powers.

In algebra, we will apply these same operations to two new types of problems. These algebra problems will have negative numbers and they will use letters to represent numbers.

Actually, we have been using both of these things in our everyday life, but when we see them in a mathematical problem, they look as if they would be very difficult to handle. We shall see that there is nothing difficult about algebra, and that it shall be a very great help on our progress through electronics. If it so happens that you have not studied algebra previously, or if you have "forgotten all you knew" about algebra, do not become discourged at this point. If you will just study through this assignment, a step at a time, you have a very pleasant surprise in store for you. You will find that algebra is a relatively simple subject and that you will master it easily!

Negative Numbers

In our study of algebra, let us first consider negative numbers.

Negative numbers are numbers which are less than zero, while positive numbers are numbers which are more than zero. Negative numbers are distinguished from positive numbers by the minus sign. Thus, -10 means 10 below zero, while +10 means 10 above zero. In most cases, +10 is written just 10. The plus sign is understood. Any number with no sign indicated is a positive number. So 17 means +17, 3 means +3, and 19.28 means +19.28. Negative numbers are used in everyday life. For example, a weather report lists a temperature of 10° below zero as -10°. An airplane pilot might think of a ten mile an hour tail wind as +10 miles an hour, and a ten mile an hour headwind as -10 miles an hour. A mechanical engineer working with steam and water pressure at a power plant might list a suction force of 2 pounds as -2 pounds per square inch of pressure.

In electronic work, we will have a great need for negative numbers. In Figure 1, for example, the wire lead connected to the battery may be either 6 volts above (+6V) or 6 volts below (-6V) ground potential depending on the way the battery is connected. In Figure 1(A), the wire lead is 6 volts more positive than ground potential, so the voltage in respect to ground would be +6V. In Figure 1(B), the voltage would be -6V. In each case we have 6 volts of electrical pressure. The + or - sign in front of the 6 volts tells us the direction of the electrical force or pressure. We know that the direction of the 6 volts is important. In all electrical circuits, the direction of the voltage determines the direction of current flow. Vacuum tube circuits will not function at all if the voltages applied to the different elements of the tube are not in the proper direction. There are many other instances when we will have to distinguish between plus (+) and minus (-) in radio work.

The absolute value of a number is its value without reference to its sign. Thus, the absolute value of +6 is 6, and the absolute value of -6 is 6.

Now that we have found out what a negative number is and why we need be concerned with negative numbers, let us proceed to find out how to perform the mathematical operations of addition, subtraction, multiplication and division using these numbers.

Algebraic Addition

Let us consider the temperature reading of 10^{0} below zero mentioned previously. This could be written algebraically as -10^{0}. What would the thermometer read if the temperature dropped 5^{0} more? Of course, we know that the thermometer would read 15^{0} below zero or -15^{0}. Notice that -5 added to -10 gives -15.

We already know how to add two positive numbers; +15 added to +10 gives +25. This demonstrates how we should add numbers with the same sign.

To add numbers with the same sign, add the absolute value of the numbers, and place the common sign in front of the answer. Thus, to add -70 and -30, add 70 and 30. This gives 100 for an answer. Then put the sign of both numbers (-) in front of the answer. The complete answer, then, is -100.

Examples of addition of numbers with the same sign are given below:

1. 192	2. -71	3. - 6.3	4. -1603.1	5. 17.2
46	-19	-18.2	- 21.4	9.6
+238	-90	-24.5	-1624.5	+26.8

6. -14.7	7. -43.06	8. 15.20	9. -43.15	10. 55.55
-6.07	- 7.02	40.06	-26.09	44.45
-20.77	-50.08	+55.26	-69.24	+100.00

Again referring back to the thermometer which is reading 10^{0} below zero, let us find what temperature would be indicated if the weather warmed up 5 degrees. We know from general knowledge that it would now be 5 below zero. To state this mathematically, -10 + 5 = -5.

Also if the weather warmed up 15 degrees, from the 10^{0} below zero point, we know that the thermometer would indicate +5 degrees. Stated mathematically this is -10 + 15 = +5.

Let us state this mathematical operation in the form of a rule.

To add numbers of unlike sign, subtract the smaller absolute number from the larger absolute number, and place the sign of the larger number in front of the answer.

To add -10 and +5 we write 10 - 5 = 5, then since 10 is the larger absolute number, we put (-) before the answer (-10 + 5 = -5). Also, to add -10 and +15 we write 15 - 10 = 5. Since the 15 is the larger number, we have a +5 for the answer. Several examples of adding numbers with unlike signs follow.

1. -10	2. +5	3. -90	4. +16	5. +72	6. -66.6	7. -30
+25	-8	+10	-17	-72	+73.4	+12
+15	-3	-80	- 1	0	+6.8	-18

These mathematical rules can be applied directly to radio circuits. In Figure 2, we have two batteries, one an 8 volt battery, and the other a 6 volt battery. We wish to know the potential difference between point x and ground. In adding voltages in a circuit such as Figure 2, we start at the point whose potential we wish to know, and list the voltages as we go around the circuit.

In Figure 2A, from point x to ground, we have +6 and +8 volts. In 2A, point x is 14 volts positive in respect to ground, or 14 volts above ground. In Figure 2B, from x to ground, we have -6V and -8V.

-6
-8
-14 Point x is -14 volts in respect to ground in Figure 2B.

In Figure 2C, from point x to ground, we have -6 and +8 volts.

-6
+8
———
+2 Point x is 2 volts positive in respect to ground.

In Figure 2D, from point x to ground we have +6 and -8 volts.

+6
-8
———
-2 Point x is -2 volts in respect to ground.

This same process has been applied to the circuits in Figure 3. Check each of these by adding the battery voltages, and see if you agree that the voltage indicated across each resistor is correct.

If more than two numbers are to be added, first add all of the numbers of like signs and then add the two sums. For example, if we wish to add -2, 4, -8, 7 and 10. First we add the numbers with like sign.

-2	4	Now add the two sums:
-8	7	21
-10	10	-10
	21	11 (answer)

Add: 42, -16, 33, 14, -18

-16	42	89
-18	33	-34
-34	14	55 (answer)
	89	

Add: -73, 44, -21, 16, -51

-73	44	-145
-21	16	60
-51	60	- 85 (answer)
-145		

For practice, add the following numbers:

1. -7, -12
2. 27, -3
3. -9, 17
4. -25, -10
5. 4, 8, 12
6. 16, -5, 4
7. 14, -5, -9
8. -17, 8, -10
9. -2, 14, -6
10. 72, -66, -18, 23, -9

Algebraic Subtraction

The rule for algebraic subtraction is:

To subtract one number from another, change the sign of the number to be subtracted and then proceed as in addition.

Examples:

Subtract -6 from 8

Subtract
8
-6
———

Change -6 to +6 and add.

8
+6
———
14 (answer)

Subtract -6 from -8

Subtract
-8
-6
———

Change -6 to +6 and add.

-8
+6
———
-2 (answer)

Subtract 6 from -8 — Subtract

-8	Change +6 to -6 and add.	-8
+6		-6
		-14 (answer)

Subtract 6 from 12

12	
-6	(Note: sign changed)
6	(answer)

Subtract -6 from 14

14	
+6	
20	(answer)

Subtract 3 from -12

-12	
-3	
-15	(answer)

Subtract -7 from -12

-12	
+7	
-5	(answer)

Subtract -12 from -7

-7	
+12	
5	(answer)

For practice, solve the following problems. Subtract the lower number from the upper number. You should be able to "mentally" change the sign of the lower number and add.

1.	2.	3.	4.	5.	6.	7.	8.
25	4	-19	-6	-8	-927	.006	-18.7
11	-2	18	-7	-6	-427	-.93	4.27
+14	+6	-37	+1	-2	-500	-.924	-22.97

Multiplication and Division

Multiplication and Division with positive and negative numbers is very simple. One easy rule tells us whether the answer is plus (+) or minus (-).

In multiplication and division, *if both numbers have the same sign* (either positive or negative), *the answer will be positive, and if the two numbers have opposite signs,* (one positive and one negative), *the answer will be negative.*

For purpose of illustration, let us divide this into four parts. First let us consider multiplication of numbers with like signs. *If two numbers have the same sign* (both positive or both negative) *their product will be positive.*

Examples: (1) 8 x 6 = 48 (2) (-8) x (-6) = 48

If two numbers have different signs (one positive and one negative) *their product will be negative.*

Examples: (3) (-8) x 6 = -48 (4) 8 x (-6) = -48

These four examples are easy to understand. Multiplication is a short-cut for addition. In example 1, we have added 8 six times. In example 2, we have subtracted -8 six times. In example 3, we have added -8 six times. In example 4, we have subtracted 8 six times.

Ten more examples of multiplication of numbers are shown below.

(5) 16 x -2 = -32	(8) -4 x 3 = -12	(12) -72 x 2 = -144
(6) -9 x -5 = 45	(9) 4 x -3 = -12	(13) -72 x -2 = 144
(7) 7 x 5 = 35	(10) -6 x -4 = 24	(14) 72 x 2 = 144
	(11) 72 x -2 = -144	

The rule for division is identical. *If the two numbers we start with are both of the same sign, the answer will be positive.*

Examples: (1) $\frac{48}{6} = 8$ (2) $\frac{-48}{-6} = 8$

If the two numbers we start with have different signs, the answer will be negative.

Examples: (3) $\frac{-48}{6} = -8$ (4) $\frac{48}{-6} = -8$

These examples are easy to understand if we consider the division problems as "check work" for our four previous multiplications.

Some more examples of division are given below:

(5) $\frac{16}{4} = 4$ (8) $\frac{-72}{24} = -3$

(6) $\frac{-16}{-4} = 4$ (9) $\frac{-72}{-24} = 3$

(7) $\frac{72}{-24} = -3$ (10) $\frac{100}{-10} = -10$

For practice, solve the following problems:

(1) $12 \times -3 =$ -36
(2) $-6.4 \times 3 =$ -18.2
(3) $-9 \times -.03 =$ .27
(4) $12 \times -14 =$ -168
(5) $-.08 \times .02 =$ -.0016

(6) $\frac{12}{3} =$ 4 (7) $\frac{-6}{3} =$ -2

(8) $\frac{-36}{-6} =$ 6 (9) $\frac{300}{-15} =$ -20

(10) $\frac{-2}{-8} =$ .25

Algebraic Terms

An algebraic term is made up of three definite components.

a. Sign. The sign of the term may be (+) or (-). We have already covered the rules for obtaining the correct sign in a problem.

b. Coefficient. The coefficient is merely a number that tells us how many units we have in the term. We worked with both signs and coefficients in the preceeding examples.

c. Literal factors. The literal factors are usually letters from the alphabet used to represent certain numbers whose value may be unknown.

In the term -3 ABC, the sign is (-), the coefficient is 3 and the literal factors are A, B, and C. We can read this term -3ABC, as minus three ABC. The term actually means -3 times A times B times C.

In the term RP, the sign is (+), the coefficient is 1, and the literal factors are R and P. When no other coefficient is shown, it is understood to be one (1). This term is read RP, and means R times P.

In the term -XYZ the sign is (-), the coefficient is 1, and literal factors are X, Y and Z. The term means, -1 times X times Y times Z.

In the term 77XYP, the sign is (+), the coefficient is 77, and the literal factors are X, Y and P.

In the term $\frac{2X}{3Y}$, the sign is (+), the coefficient is $\frac{2}{3}$, and the literal factors are X and Y. This term could be read as two X divided by three Y, or as two X over three Y, or as $\frac{2}{3}$ X over Y. The term actually means 2 times X all divided by 3 times Y.

Thus, we see that 3A means 3 times A, and AB means A times B.

In algebra, the letters or literal factors, are generally used in place of numbers. Sometimes the numbers for which these letters are used are known, and sometimes they are unknown. Let us find the value of some terms when we know the value of the literal terms.

Assume, a = 6, b = 2, c = 3

Example 1. 3abc = 3 x a x b x c. Now substituting the numbers which each letter is equal to in the problem we have: 3abc = 3 x a x b x c = 3 x 6 x 2 x 3 = 108.

Example 2. $\frac{2bc}{5a} = \frac{2 \times 2 \times 3}{5 \times 6} = \frac{12}{30} = \frac{2}{5}$ or .4

Example 3. -6bc = -6 x 2 x 3 = -36

Example 4. $\frac{-3ab}{-ac} = \frac{-3 \times 6 \times 2}{-6 \times 3} = \frac{-36}{-18} = 2$

Using the same values for a, b, and c as in the Example 1, 2, 3, and 4, find the value of the terms in the four problems below.

1. 7ac = 126 2. $\frac{72}{-abc}$ = -2 3. $\frac{-6a}{bc}$ = -6 4. -5bc = -30

In the next four problems, assume that f = 2, g = -3, h = 7, k = -4. Find the numerical value of each of these terms.

5. $\frac{gk}{f}$ = 6 6. $\frac{49f}{gk}$ = 8.16 7. 3 kgfh = 504 8. $\frac{-2k}{g}$ = -2 2/3

Kinds of Algebraic Expressions

The algebraic expressions we have dealt with so far have been *Monomials*. Monomial is a fancy way of saying *one term*. Any number of numbers and literal factors may be multiplied together, or divided and still remain a monomial, but any time addition or subtraction occurs in an algebraic expression, the expression is no longer a monomial. For example, 6XYZQ is a monomial and 7BCDEF is also a monomial, but 7BC + DEF and 7BC - DEF are *not* monomials. In the expression 7BC + DEF, we have two terms. The two terms are 7BC and DEF. This algebraic expression is called a *Binomial*.

In the expression 5c - 3ab + 27, we have three terms. This expression is a *Trinomial*.

All expressions having more than one term may be called *Polynomials*. Polynomial means many terms.

Algebraic terms frequently have exponents in them. We worked with exponents when we studied Powers of Ten. Remember, 10^5 meant 10 x 10 x 10 x 10 x 10. In the term, 10^5, the base is 10 and the *exponent* is 5. The exponent indicates the number of times the base is to be multiplied by itself. In the term, A^5, A is the base and 5 is the exponent. This term means A x A x A x A x A. Likewise, B^6 means B x B x B x B x B x B. The term C has an exponent of 1 understood, and can be written C^1. The term ab^2 means a x b x b, and the term $m^2n^2y^3$ means m x m x n x n x y x y x y.

When we were studying powers of 10, we found that to multiply terms, we added the exponents. Thus $10^3 \times 10^2 = 10^{3+2} = 10^5$. Likewise, the terms $a^3 \times a^2 = a^{3+2} = a^5$. This is logical when we consider what a^3 and a^2 means. The term a^3 means a x a x a, and a^2 means a x a. Then a^3 x a^2 means a x a x a times a x a, or a x a x a x a x a or a^5. To stage this in the form of a mathematical law we could say, when the bases are the same (the base is the number which is to be multiplied by itself), we add exponents in multiplication. Then $b^5 \times b^2 = b^7$ and $y^2 \times y^6 = y^8$. But a^2 times b^3 has to be written as a^2b^3. Since the bases are not the same, we cannot combine exponents.

In division, literal factors of the same base are combined by subtracting their exponents. Thus $X^3 \div X^2 = X^{3-2} = X^1$ or X. Remember we did the same thing when dealing with powers of 10. For example, $10^3 \div 10^2 = \frac{10^3}{10^2} = 10^{3-2} = 10^1$ or 10. Also, $\frac{X^4Y^3}{X^2Y} = X^{4-2}Y^{3-1} = X^2Y^2$.

Several examples involving the multiplication and division of terms containing exponents follow:

Examples:
1. $C^2 \times C = C^{2+1} = C^3$
2. $2D^5 \times D^2 = 2 \times D^{5+2} = 2D^7$
3. $ab \times a^2b^2 = a^{1+2}b^{1+2} = a^3b^3$
4. $abc \times a^2b^2d = a^{1+2}b^{1+2}cd = a^3b^3cd$
5. $D^5 \div D^2 = \frac{D^5}{D^2} = D^{5-2} = D^3$
6. $X^2Y^2 \div XY = \frac{X^2Y^2}{XY} = X^{2-1}Y^{2-1} = XY$
7. $\frac{a^2b^2c^2}{ab} = a^{2-1}b^{2-1}c^2 = abc^2$
8. $\frac{x^2y^2z^2c}{y^2} = x^2y^{2-2}z^2c = x^2z^2c$

For practice, solve the following problems:

1. $b \times b =$
2. $b \times b^2 =$
3. $c^2 \times c^8 =$
4. $XYZ \times 2XY =$
5. $a^2b^2 \div b =$
6. $XY^2Z^2 \div XYZ =$
7. $c^3d^2e \div c^2e =$
8. $y^5x^3 \div y^3x^3 =$

The term $2y^2$ means 2 x y x y. Notice that only the literal factor (y in this example) is squared. The term $(2y)^2$, means to square the entire term 2y. This is equal to 2y x 2y = 2 x 2 x y x y or $4y^2$.

In addition and subtraction we can only combine terms whose literal factors are identical (the same letter and the same exponent).

Examples: (1) $2X + 3X = 5X$ (2) $4A - 7A = -3A$

(3) $2B + 5C - 6C = 2B - C$ (4) $3A + 5A^2 - 1A^2 = 3A + 4A^2$

The process of combining the like terms in an algebraic expression is called *combining terms*.

Examples of combining terms are given below.

(1) Add 3XY, 4abc, 2XY, -2abc, 10

The 3XY and the 2XY can be combined since they have identical literal factors. 3XY + 2XY = 5XY. The 4abc and the -2abc can be combined. 4abc - 2abc = 2abc. The entire expression is then equal to 5XY + 2abc + 10.

(2) Add −6E, 14R, 3E, −5R

The easiest way to combine such terms is to place them in columns, placing terms with identical literal factors in the same column, and then adding.

Solution:

$$\begin{array}{r} -6E \qquad \\ 3E \qquad \\ 14R \\ \underline{-5R} \\ -3E + 9R \end{array} \text{ (answer)}$$

(3) Add 3A + 5B, 2A − 7B, B + C

$$\begin{array}{l} 3A + 5B \\ 2A - 7B \\ \underline{\quad\;\; B + C} \\ 5A - \;\, B + C \end{array} \text{ (answer)}$$

(4) Add $13XYZ - 2XY^2Z$, $5XY^2Z - 27XYZ$

Solution:

$$\begin{array}{l} 13XYZ - 2XY^2Z \\ \underline{-27XYZ + 5XY^2Z} \\ -14XYZ + 3XY^2Z \end{array} \text{ (answer)}$$

(5) Subtract 3A + 5B, from 2A − 7B + C

Solution: 2A − 7B + C

Subtract: $\underline{3A + 5B}$

Remember that algebraic subtraction is performed by changing the sign of the lower quantity in the problem and then adding.

Changing the sign of the lower quantity we have:

$$\begin{array}{l} 2A - 7B + C \\ \underline{-3A - 5B \qquad} \\ -\;A - 12B + C \end{array} \text{ (answer)}$$

(note we had to change the sign of *each term* in the lower number)

(6) Subtract 6XY from 3XY

$$\begin{array}{l} 3XY \\ \underline{-6XY} \\ -3XY \end{array} \text{ (answer)}$$

(7) Subtract 17a − 4b from 3a − b

Solution:

$$\begin{array}{r} 3a - b \\ \underline{-17a + 4b} \\ -14a + 3b \end{array} \text{ (answer)}$$

(8) Subtract $3a^2b - d$ from $7xy + d$

Solution:

$$\begin{array}{r} 7xy + d \\ \underline{-3a^2b \qquad\quad + d} \\ -3a^2b + 7xy + 2d \end{array} \text{ (answer)}$$

For practice, solve the following problems:

1. Add 6A, 9B, −3A, 3B = 3a + 12b
2. Add 13a + 5b, −7a − 10b, a − 4b = 7a − 9b
3. Add 16XY + 3ab, 6ab − 4XY 12xy + 9ab
4. Subtract 7X from 19X = 12X
5. Subtract $6a^2b + 3ab^2$, from $11a^2b + ab^2$ = $5a^2b - 2ab^2$
6. Subtract 16yx − 3mn from 13yx − 4mn − 3yx − mn

Signs of Operation

Before we can conveniently use binomials, trinomials and polynomials, certain symbols or Signs of Operation are needed. These Signs of Operation are used merely to reduce the amount of written work in the solution of algebraic problems.

The most commonly used signs of operations are:

a. Parentheses ( )

b. Brackets [ ]

c. Braces { }

Notice that we always use these symbols in pairs. Parentheses, Brackets and Braces all have the same meaning. They indicate that all the terms inside are to be considered as one quantity.

Thus: (7A) means 7A, and 4B + (2C) means 4B + 2C.

-(3A + 4B - C) indicates that we are to subtract 3A + 4B - C from some other quantity, or from zero. Remember our rule for subtraction: "Change the sign and add". If we remove this set of parentheses we change *each* sign.

Thus: -(3A + 4B - C) = -3A - 4B + C

Also: 3(3A + 4B - C) indicates that we are to multiply 3A + 4B - C by 3.

Thus: 3(3A + 4B - C) = 9A + 12B - 3C.

Likewise, -2(4A -6C + 2) = -8A + 12C - 4. Notice that all we really did in this last case was to multiply the three terms inside the parentheses by -2.

If we have -8(A - 3B + 4A + B - C + 2A) it is best to collect terms within the parentheses before we multiply by -8.

Thus: -8(A - 3B + 4A + B - C + 2A) = -8(7A - 2B - C) = -56A + 16B + 8C.

In the algebraic expression: 2 + 3(4 - 2a + b - 3a) we first collect terms inside the parentheses and we have 2 + 3(4 - 5a + b). Next multiply the terms within the parentheses by 3. This gives 2 + 12 - 15a + 3b. Again collecting terms, the final answer is 14 - 15a + 3b.

Notice that the 2 was not involved with the parentheses.

Another example indicating the use of parentheses follows.

6B + 7C -(4B + 5C - D + C) = First collect terms within the parentheses.

6B + 7C -(4B + 6C - D) = Removing the parentheses, we have to change the signs of each term in the parentheses due to the minus sign before the parentheses. 6B + 7C - 4B - 6C + D = Then collect terms; 2B + C + D (Answer.)

We will now work a longer problem containing parentheses and brackets. Notice that in removing signs of operation we start with the innermost signs.

Example: 2[3a + 2(a + b)] =

First we start with terms in parentheses.

2[3a + 2a + 2b] =

Now we collect terms.

2[5a + 2b] =

Now we remove the brackets.

10a + 4b (answer)

Example: 3 + 2a{5 - b + 2[3 - 2(a + b) - 4 + 3(a + b - 3a) + 2] -3a}

Collecting terms: 3 + 2a{5 - b + 2[3 - 2(a + b) - 4 + 3(-2a + b) + 2] -3a}

Removing parentheses: 3 + 2a{5 - b + 2[3 - 2a - 2b - 4 - 6a + 3b + 2] - 3a}

Collecting terms: 3 + 2a{5 - b + 2[1 - 8a + b] - 3a}

Removing brackets: 3 + 2a{5 - b + 2 - 16a + 2b - 3a}

Collecting terms: 3 + 2a{7 + b - 19a}

Removing braces: 3 + 14a + 2ab - $38a^2$ (answer)

For practice solve problems 1 through 10. Simplify the expressions by removing signs of operation. Answers have been given for the first three problems. Check the answers before proceeding with the remaining 7 problems. The terms in your answers need not appear in the same sequence as shown in Problems 1, 2 and 3. Thus $5a + 3b - 13c$ could also be written as $3b + 5a - 13c$ or $-13c + 5a + 3b$ etc.

1. $4a + 5b - 10c - (3c + 2b - a) = 5a + 3b - 13c$
2. $3(a - b - 4a + 5) + 2 - 6a(b + 3) = -27a - 3b - 6ab + 17$
3. $4 + 3\,[b - 2a(a + b - 3a + 3) + 2b] = 12a^2 - 18a - 6ab + 9b + 4$
4. $7(2a) + 5(3b) =$ $14a + 15b$
5. $3(a + c) - 4(a - b - c) =$ $-7c + 4b - a$
6. $5 + 2(10 - 6a + 5 - 4b + 3 - a) =$ $41 - 14a - 8b.$
7. $3[a + 2(b + c)] =$ $3a + 6b + 6c$
8. $2(a + b) + 6(b + c) - 4(a - c) =$ $-2a + 8b + 10c.$
9. $6 - 4[5 - 3(a - 8) + 2(6 - a - 10) + 2] =$ $7a - 86$
10. $7a - 4[4 - (a - 3) + 2(b + 3) + 4a] =$ $-52 - 5a - 8b.$

Multiplication of Polynomials

The terms $2abc$ mean $2 \times a \times b \times c$. Also the term $(2)\ (a)$ means $2 \times a$ or $2a$. $(3b)\ (4c)$ means $3b \times 4c$ or $12bc$.

It follows that $(3+4)\ (6 - 2)$ means $(3+4) \times (6 - 2)$. $(3+4) = 7$, and $(6-2)$ equals 4, so the term $(3 + 4)\ (6 - 2)$ is equal to $(7)(4) = 28$.

We could also obtain the answer, 28, in the following manner:

Multiply the 3 by the 6 and then by -2.

Multiply the 4 by the 6 and then by -2.

Sum up the four products.

Thus: $(3 + 4)\ (6 - 2) = 18 - 6 + 24 - 8 = 28$

Notice that we multiply the first number in the first term by *each* of the numbers in the second term. Then we multiply the second number in the first term by *each* number in the second term. Then we sum up the four products.

This will be demonstrated in the examples below.

Example 1. $(4 - 3)\ (7 - 2) = 28 - 8 - 21 + 6 = 5$

Example 2. $(6 + 2)\ (3 - 4) = 18 - 24 + 6 - 8 = -8$

We will use this same method in multiplying algebra expressions containing more than one term.

Thus: $(a + 6)(a - 3) = a \times a - 3 \times a + 6 \times a - 18 = a^2 - 3a + 6a - 18 = a^2 + 3a - 18.$

Also: $(a^2 - 3)(7 - b) = 7a^2 - a^2b - 21 + 3b$

In these examples we have used the same method outlined above.

Additional problems of this nature are given below:

Example 1. $(4C - b)(7 - 2d) = 28C - 8Cd - 7b + 2bd$

Example 2. $(3a^2 - b)(2a - b) = 6a^3 - 3a^2b - 2ab + b^2$

Example 3. $(9X + 7Y)(X + Y) = 9X^2 + 9XY + 7XY + 7Y^2 = 9X^2 + 16XY + 7Y^2$

Example 4. $(a + 7)(10 - a^2 + a) = 10a - a^3 + a^2 + 70 - 7a^2 + 7a = 17a - a^3 - 6a^2 + 70$

Notice that in this problem there were three terms in the second parentheses, but we applied the same rule and multiplied each term in the first parentheses times *each term* in the second parentheses. Example 5 shows another such problem.

Example 5. $(3 - M)(10 + M^2 + M^3) = 30 + 3M^2 + 3M^3 - 10M - M^3 - M^4 =$
$30 + 3M^2 + 2M^3 - M^4 - 10M$

Note in Example 4 and 5, the answers are correct, but are not considered to be in the best form. To state the answers to Example 4, $17a - a^3 - 6a^2 + 70$, we should write it $-a^3 - 6a^2 + 17a + 70$. This has the literal factors arranged with powers in descending order. The $-a^3$ is the highest power in the term so should be written first. The $-6a^2$ is the next highest power so should come next. The next highest power is the 17a and last of all is the +70.

The answer to Example 5 should be written $-M^4 + 2M^3 + 3M^2 - 10M + 30$.

Example 6. $(a + b)(a - b) = a^2 - ab + ab - b^2 = a^2 - b^2$

For practice solve the following problems:

1. $(6 + b)(a + 3) =$ $6a + 18 + ab + 3b$
2. $(c - 4)(5 - c) =$ $5c - c^2 - 20 + 4c = c^2 + 9c - 20$
3. $(a^2 + 3)(a + 6) =$ $a^3 + 6a^2 + 3a + 18$
4. $(X + Y)(X - Y) =$ $x^2 - xy + xy - y^2 = x^2 - y^2$
5. $(a + 6)(a^2 + a + 1) =$ $a^3 + a^2 + a + 6a^2 + 6a + 6 = a^3 + 7a^2 + 7a + 6$

Division of Polynomials

A method quite similar to long division in arithemetic may be used when dividing expressions containing several terms.

For example, let us divide $(a^2 + 2ab + b^2)$ by $(a + b)$.

Write the problem in the form of a long division problem.

Example 1. $a + b \overline{\big)\, a^2 + 2ab + b^2}$ Then we see how many times the first term in the divisor will go into the first term in the dividend.

In this case, a will go into a^2, a times, so a is the first term in the answer.

$$\begin{array}{r|l} & a \\ \hline a + b & a^2 + 2ab + b^2 \\ & \underline{a^2 + ab} \end{array}$$

Multiply a times a + b, and put the product below the terms in the dividend as shown.

$$\begin{array}{r|l} & a \\ \hline a + b & a^2 + 2ab + b^2 \\ & \underline{a^2 + ab} \\ & \qquad ab + b^2 \end{array}$$

Subtract the product $(a^2 + ab)$ from $a^2 + 2ab + b^2$.

Now the first term in the divisor a, goes into ab, +b times, so +b is the next term in the answer.

$$\begin{array}{r|l} & a + b \\ \hline a + b & a^2 + 2ab + b^2 \\ & \underline{a^2 + ab} \\ & \qquad ab + b^2 \end{array}$$

Then the multiplying (a + b) times b, enter the product as shown and subtract. There is no remainder, so the problem works out evenly.

$$\begin{array}{r|l} & a + b \\ \hline a + b & a^2 + 2ab + b^2 \\ & \underline{a^2 + ab} \\ & \qquad ab + b^2 \\ & \qquad \underline{ab + b^2} \end{array}$$

The answer is $a + b$.

To check the answer, multiply the answer by the divisor, and the dividend should be the product.

Check: $(a + b)(a + b) = a^2 + ab + ab + b^2 = a^2 + 2ab + b^2$.

Example 2. Divide $(14 + X^3 - 2X^2 + 4X)$ by $(X - 3)$

$$\begin{array}{r|l} & \\ \hline X - 3 & X^3 - 2X^2 + 4X + 14 \end{array}$$

Notice that we rearranged the terms and placed X^3, the highest power of X first, and so on down to 14, the term containing no powers of X. This greatly simplifies our work.

$$\begin{array}{r|l} & X^2 \\ \hline X - 3 & X^3 - 2X^2 + 4X + 14 \\ & \underline{X^3 - 3X^2} \\ & \qquad X^2 + 4X + 14 \end{array}$$

The first term in the answer is X^2, since X will go into X^3, X^2 times. We multiply X^2 times $X - 3$, and subtract the product.

$$\begin{array}{r|l} & X^2 + X \\ \hline X - 3 & X^3 - 2X^2 + 4X + 14 \\ & \underline{X^3 - 3X^2} \\ & \qquad X^2 + 4X + 14 \\ & \qquad \underline{X^2 - 3X} \\ & \qquad\qquad 7X + 14 \end{array}$$

The next term in the answer is X. We multiply X - 3 times X and subtract the product.

$$\begin{array}{r|l} & X^2 + X + 7 \\ \hline X - 3 & X^3 - 2X^2 + 4X + 14 \\ & \underline{X^3 - 3X^2} \\ & \qquad X^2 + 4X + 14 \\ & \qquad \underline{X^2 - 3X} \\ & \qquad\qquad 7X + 14 \\ & \qquad\qquad \underline{7X - 21} \\ & \qquad\qquad\qquad 35 \end{array}$$

The next term in the answer is +7. We multiply (X - 3) times 7, and subtract the product.

There is a remainder. It is the same as a remainder in long division and can be shown by a fraction.

Answer: $X^2 + X + 7 + \frac{35}{X - 3}$

Example 3. Divide $(x^3 - y^3)$ by $(x - y)$

$$\begin{array}{r|l} & x^2 + xy + y^2 \\ \hline x - y & x^3 \qquad\quad - y^3 \\ & \underline{x^3 - x^2y} \\ & \qquad x^2y - \qquad y^3 \\ & \qquad \underline{x^2y - xy^2} \\ & \qquad\qquad xy^2 - y^3 \\ & \qquad\qquad \underline{xy^2 - y^3} \\ & \qquad\qquad\qquad 0 \end{array}$$

We have an x^2 and x term missing. We leave blank spaces for the missing terms. Check the answer by multiplying $(x^2 + xy + y^2)(x - y)$.

Example 4. Divide $(12x^2 - 36y^2 + 11xy)$ by $(-4x - 9y)$

Do not be discouraged if you find these long division problems difficult. Study them carefully to learn the proper method of working them, and you will discover that they are much easier than they appear at a glance. Try solving Example 4 without looking at the solution given, and compare your work with the example. Do this also for a couple of the other examples.

$$
\begin{array}{r|l}
 & -3x + 4y \\
\hline
-4x - 9y & 12x^2 + 11xy - 36y^2 \\
 & \underline{12x^2 + 27xy} \\
 & \quad - 16xy - 36y^2 \\
 & \quad \underline{- 16xy - 36y^2} \\
 & \qquad 0
\end{array}
$$

Notice the $-3x$ in the answer. We have to multiply $-4x$ by minus $3x$ in order to obtain plus $12x^2$. Check the answer by multiplying $(-4x - 9y)(-3x + 4y)$

For practice, solve the following problems:

1. Divide $(m^2 - 2mn + n^2)$ by $(m - n)$ Ans. $(m - n)$

2. Divide $(X^2 - Y^2)$ by $(X + Y)$ $X - Y$

3. Divide $(X^3 - Y^3)$ by $(X - Y)$ $X^2 + XY + Y^2$

4. Divide $(a^2 + 2ab + b^2)$ by $(a + b)$

In this assignment, we have learned how to perform the fundamental operations of algebra. We have learned what negative numbers are and how to use them. We learned how to add, subtract, multiply and divide algebraic terms containing letters in place of numbers. Perhaps you have noticed that most of the problems in this assignment were exercises in handling algebraic quantities. Most of them cannot be applied directly to electronic circuits, but were presented in this assignment for the purpose of familiarizing you with the various operations of algebra.

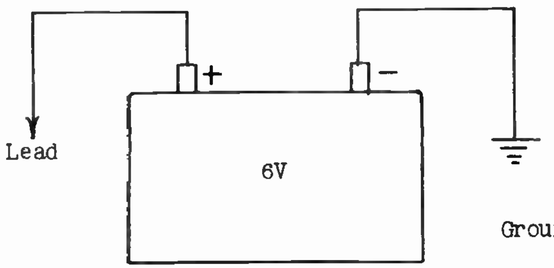
We have now mastered all of the fundamental operations of algebra, and in a future assignment, we will apply these fundamentals in solving some very practical electronic problems.

Test Questions

Be sure to number your Answer Sheet Assignment 10.
Place your Name and Associate Number on *every* Answer Sheet.
Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

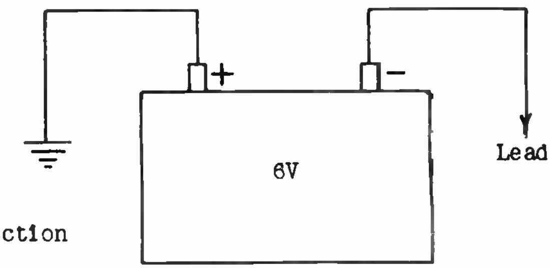
In answering these algebra problems, *show all of your work. Draw a circle around your answer.* Do your work neatly and legibly.

1. Add 70, -41, 23, -21.
2. Multiply -63 by -27.
3. Divide 144 by -12.
4. If a = 2, b = 3, and c = 4, what is the numerical value of 4abc?
5. Add 6c + 7d, 9c - 6d.
6. Subtract 6a + 7b from 17a + 17b.
7. Simplify 3(a + b + c) + 4b.
8. Multiply (a + 3)(a - 3).
9. $B^3 \times B^7 =$
10. $B^7 \div B^3$

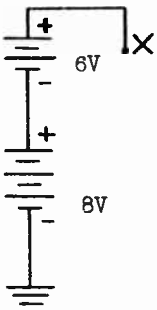


1A

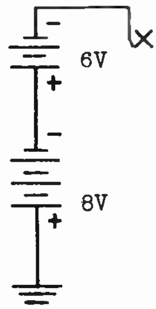
Ground Connection



1B



2A



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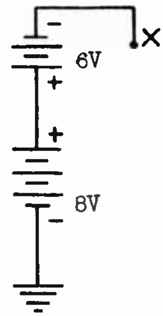
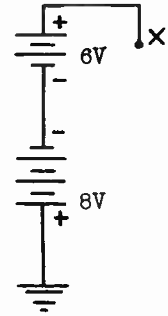
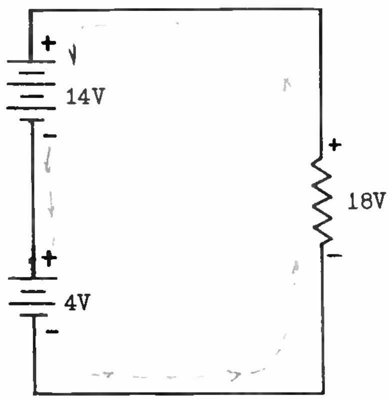


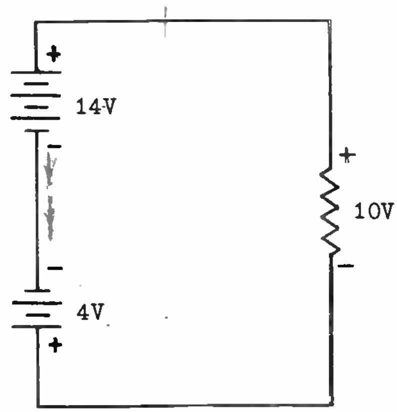
2C



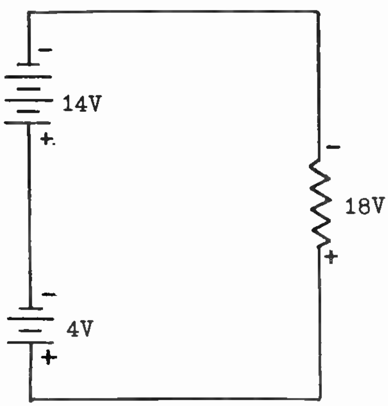
2D



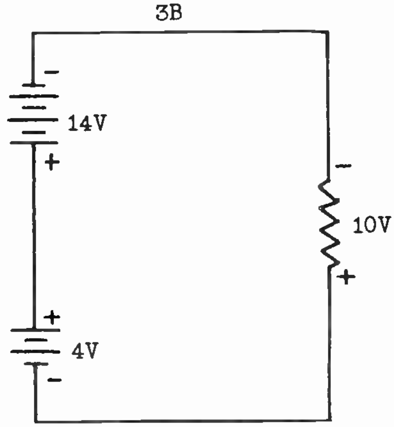
3A



3B



3C



3D

Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

DIRECT CURRENT MEASURING INSTRUMENTS

ASSIGNMENT 11

ASSIGNMENT 11

DIRECT CURRENT MEASURING INSTRUMENTS

In 1883 Lord Kelvin wrote these words - - - - - - - -

I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind. It may be the beginning of knowledge but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be.

These are certainly appropriate words for the electronics and television industry, for a great deal of the progress in the development of this industry can be traced directly to the availability of suitable measuring instruments.

Striking perhaps closer to home, the electronic and television technician is completely dependent upon his measuring instruments, for only by measuring various currents, voltages, and resistances, can he determine any source of trouble. The automobile mechanic, for example, can see or feel that a certain part is worn or broken and needs replacing, but it is impossible to tell by looking or feeling whether or not an electronic component, such as a resistor, is acting properly. Consequently, we must measure the current oo voltage drop in such a resistor, and perhaps its resistance value, to definitely establish the source of trouble.

There is some confusion among electronic and television technicians as to the proper name for electrical measuring equipment. An *instrument* has been defined by the American Institute of Electrical Engineers as "a device for measuring the present value of the quantity under observation", whereas, a *meter* has been defined as "a device for measuring and registering the total sum of an electrical quantity with respect to time". Thus, by these definitions, milliammeters, ammeters, voltmeters, wattmeters, and similar devices measuring the current, voltage, or power *at a given instant* are properly called instruments, whereas, the familiar watt-hour meter, which measures the quantity of electric energy taken over a period of time, is properly called a meter. the average electronic and television technician, however, frequently refers to any of his instrument-type test equipment as a meter, and this procedure will be followed here.

The Effects of Electricity

We have learned that an electric current is a slow progression of electrons passing a point in a circuit, with 6.28×10^{18} electrons per second constituting a current of one ampere. However, rather than count these electrons in order to measure the current, we take the easy way out and measure the *effects* of an electric current or voltage rather than the current or voltage itself.

There are a number of different effects that an electric charge or an electric current can produce. For example, we learned in our study of dry cells and batteries that when certain chemicals were brought together, electricity was produced. Consequently, there is a connection between chemical action and electricity.

We also learned in our study of magnetism, that an electric current will produce a magnetic field; this would be a magnetic effect.

The ordinary electric toaster or flat iron is an example which shows that electricity can produce a heating effect.

In our study of static electricity, we learned that like electric charges have a repelling effect; whereas, unlike electric charges have an attracting effect. These effects are called the electrostatic effects.

Electricity, then, under the proper conditions, will produce four entirely different effects; chemical, magnetic, heating, and electrostatic. If we measure the amount, or value, of any one of these effects, for all practical purposes we will have the same information as though we had measured the electric current or charge itself.

There are, in common use today, two basic kinds of electricity known as direct current and alternating current. In this assignment we will study only the instruments and meters designed to measure direct current, and then we will adapt some of these for alternating current in a later assignment.

Direct Current Instruments

Almost without exception, every instrument for measuring an electric charge or current consists of two parts, one movable and one stationary. The force which determines the amount of motion of the movable part is determined by the size or amount of the electric current being measured, and, in most cases, this force is the result of a magnetic effect. Most instruments have two magnetic members, one of which must be variable in strength. Either of these members may take the form of a permanent magnet, a temporary or induced magnet, or a wire carrying a current.

In certain other types of instruments, the moving member is caused to move by the expansion of a piece of wire heated by an electric current. In still another type, the moving force is brought about by the electrostatic attraction of two oppositely charged plates, one of which is free to move toward the other. But in every case, the moving member drives a pointer across a scale which can be calibrated in terms of volts or amperes.

In 1820, Hans Christian Oersted discovered the phenomenon upon which the modern meters, which are used to measure currents, operate. He noticed that a compass needle, when placed near a wire carrying an electric current, moved from its original direction, as shown in Figure 1. The larger the current, the greater was the deflection and large currents made the compass needle stop at nearly right angles to the wire. Also, if the current were reversed, the needle deflection would be in the opposite direction.

The underlying principle of this instrument is the fundamental law of magnetism which we have already studied. *Like magnetic poles repel.* The current flowing through the wire sets up a magnetic field around the wire. This magnetic field interacts with the magnetic field of the compass needle. Since the compass needle is free to rotate, the repulsion between its magnetic field and the magnetic field of the wire causes the compass to be deflected from north.

This was the skeleton of an instrument mechanism, but a great many improvements have been made on it.

In our study of magnetism, we learned that we could increase the magnetic field around a wire, with a given amount of current flowing through the wire, if we wound the wire in the form of a coil. Such an instrument is shown in Figure 2. The advantage of this instrument over the crude one of Oersted's is that a smaller amount of current is required to produce a certain amount of deflection of the compass needle. To illustrate this, let us assume that in Oersted's instrument, a current of 10 amperes would have to be flowing through the wire to produce a 15 degree deflection of the compass needle. In the instrument of Figure 2, one ampere of current flowing through the coil might produce this same 15 degree deflection of the compass needle. The instrument in Figure 2 is said to be *more sensitive* than the one in Figure 1.

The instrument illustrated in Figure 2, which is called a "tangent galvanometer", can be quite accurate when used properly but has the disadvantage that its performance involves the earth's magnetic field, which varies from place to place, in both direction and magnitude. The use of this instrument is a rather complicated process, and for this reason it is used for demonstration purposes only.

The D'Arsonval Movement

In 1888, Arsine D'Arsonval, a Frenchman, applied these same principles to a slightly different instrument. This type of instrument is called a D'Arsonval movement, and is used in almost all modern electrical instruments.

A working sketch of the D'Arsonval movement is shown in Figure 3 and a phantom-type photograph of such an instrument is shown in Figure 4. A permanent magnet of an alloy, such as tungsten steel, cobalt steel, or aluminum-nickel-cobalt (alnico), produces a strong magnetic field, and there is mounted in this field, a coil of fine wire which is pivoted and free to move. Thus, in this instrument, the coil moves while the magnet is stationary, permitting the use of a much stronger magnetic field than that of the earth. Again, it can be seen that the instrument operates because an electric current is passed through the turns of wire. The relative positions of the permanent magnet and the moving coil may be seen in Figures 3 and 4.

Polarity of the permanent magnet is shown in Figure 3. When no current is being passed through the coil, it is held in the position shown by the two small spiral springs, one at either end of the coil. These springs also serve to conduct the current to and from the coil.

When current is passed through the coil it becomes an electromagnet, the polarity of its field being indicated by the dotted arrow in Figure 3. The repulsion by the two N-poles and also by the two S-poles produces a rotation of the coil in a clockwise direction. The coil rotates until the actuating force of magnetic repulsion is balanced by the restoring force of the two springs. As the coil rotates, a pointer attached to it moves up a scale. This scale may be calibrated to indicate the amount of current flowing through the coil.

The phantom-view photograph of Figure 4 illustrates some of the improvements in the modern instrument, compared to the basic unit illustrated in Figure 3. In Figure 4, we see that soft iron pole pieces have been added to the magnet to concentrate the magnetic field in the region surrounding the coil. To increase this effect, a cylindrical piece of magnetic material has been placed inside the moving coil. This magnetic core is stationary, and does not rotate with the moving coil. The coil rotates in the small circular gap between the pole pieces of the magnet and the cylindrical core. The magnetic field in this region is very strong. This makes the instrument more sensitive.

The moving coil is wound on a small aluminum frame. In addition to providing a light form on which to wind the coil, this aluminun frame acts to *dampen* the meter movement. Without this *dampening action*, the meter will oscillate. That is, when a current is passed through the meter, the pointer will swing up-scale and pass the proper point. Then it will come to a stop and swing down-scale past the proper point, come to a stop and swing up-scale again. This back and forth action will continue, with the pointer stopping closer to the correct reading each time, until finally it stops on the proper point. Anyone wishing to make a reading with the undamped meter will have to wait for it to stop "swinging around" the proper point (oscillating) before making the reading. In the *damped* meter, the pointer will swing more slowly and come to rest at the proper point without oscillation. This damping action occurs because the aluminum frame forms a complete loop or turn. As it moves through the magnetic field, a current will be set up in the frame, and the magnetic field set up by this current will oppose the motion. This makes the pointer move more slowly, and it will not swing past the proper point.

The V-shaped part which may be seen in Figure 4, directly in front of the moving coil, is the zero adjustment of the meter. As this part is moved it varies the pressure produced by the spiral spring seen in the front of the coil in Figure 4. This will cause the pointer to move slightly about its zero position. This adjustment is made by turning the small screw which may be seen directly below the meter face in Figure 5. By turning this zero adjusting screw, the meter pointer may be made to fall exactly on zero when no current is flowing through the instrument.

Figure 5 shows a typical panel mounting meter which will measure currents up to one milliampere.

The D'Arsonval instrument can be made extremely accurate, very sensitive and reasonably rugged. Tests made at the National Bureau of Standards have shown that, after a half-century of constant use and no repairs, they still yield results within the 0.5 percent accuracy guaranteed by the manufacturer.

The sensitivity of such an instrument depends on the strength of the permanent magnet and the number of turns of wire which are put on the moving coil. Instruments have been made using more than 2000 turns of copper wire having a diameter less than one third the diameter of a human hair. Sensitivity is a measure of *how small* a current produces full scale reading on the meter. Thus, a meter that gives a full scale reading when one milliampere of current is flowing through it is ten times as sensitive as one which requires 10 milliamperes of current for full scale deflection.

So sensitive can the modern permanent-magnet moving-coil type of instrument be made, that, in one portable type, a current of only five millionths of an ampere produces full-scale deflection on a scale approximately 6 inches in length. Ordinarily, a person with moist fingers can drive the pointer across the scale merely by touching the terminals. Yet, sensitive as this instrument is, it can be constructed to be very portable. Such instruments are often made in small cases with a carrying handle, and can be carried to the equipment to be tested without damage to the instrument as long as reasonable precaution is observed in handling.

D-c meters are made with a wide variety of sensitivities. A great majority of them are made with a sensitivity of one milliampere for full scale deflection. We shall see later in this assignment that it is possible to use a meter to indicate a higher value of current than that for which it is designed by using shunt resistors.

The full-scale current sensitivity of other popular meters are 10 ma., 500 μ a. and 50 μ a.

The moving coil in all meters is made of wire (usually copper) and, of course, has some resistance. The resistance of the coil is called the *internal resistance* of the meter.

Meter Accuracy

All meters lack perfection, but for the average practical work extreme accuracy is not required, and 5% accuracy is usually satisfactory. Meter inaccuracies may be due to several causes. For one thing, the meter cannot be calibrated perfectly. The scales are printed from a drawing which is based on a typical meter of the type considered. However, not all bearings, springs, magnets, and coils are exactly alike and slight variations in responding to the same current will result. The same current, therefore, may give slightly different readings on several similar meters. The meter accuracy also depends upon errors due to the associated resistors used with the meter, and to the width of the pointer. Most responsible meter manufacturers will guarantee their products to be accurate to within plus or minus 2% when it leaves the factory, and to hold its accuracy to within plus or minus 5% with reasonable care in the field.

Now that we have seen how direct-current meters operate, let us learn the proper way to read a meter.

Reading a Meter

In order to obtain as accurate a reading as possible from a meter, we must be careful to place our eye directly in front of, or above the pointer. Figure 6 shows what might happen if we do not do this. Since the meter pointer is normally between one sixteenth and one eighth of an inch away from the scale, an inaccurate reading will result if we look at the meter from an angle, as illustrated.

Expensive, highly-accurate laboratory type measuring instruments usually have a mirror built into the scale; and to properly use such an instrument, we place our eye so that the image of the pointer in the mirror is directly behind the pointer itself, or until we can no longer see the image of the pointer because the pointer itself is in the way.

Study the enlarged meter scale shown in Figure 7. The 0, 1, 2, 3, 4 and 5 are the numbers which would appear on the meter scale. The numbers printed above the scale do not appear on an ordinary meter scale, but are included in the figure to aid in learning to read a meter. If various readings on this scale can be correctly read, you should have no difficulty with other meter readings.

When the pointer stops on any of the marked divisions, 1, 2, 3, 4, or 5, the reading will simply be the printed number for that division line.

When the pointer stops on one of the small unmarked divisions, note the value of the marked divisions on either side, then figure out the value of the mark under the pointer just as you would figure out the value of one of the marks between the inch marks on a ruler.

In Figure 7, note that there are 5 small divisions between each marked division, therefore each small division is equal to 2 tenths of one milliampere. Thus, if the pointer were to stop on the first small division above the 2, the correct reading would be 2.2 ma. If the pointer were to stop on the third division above the 4, the correct reading would be 4.6 ma.

If the pointer stops half way between two small division marks, figure out the value of the two small divisions, then read a value half way between them. For example, if the pointer were to stop half way between the first and second small divisions above 1 on the meter scale shown in Figure 7, the correct reading would be 1.3 ma., since the first mark above 1 is 1.2 ma. and the second mark above 1 is 1.4 ma.

If a pointer does not fall directly on a division mark, it is entirely adequate, in electronic work, to estimate the reading. Study the meter scale shown in Figure 7 until you are satisfied that you can read the meter correctly with the pointer at any given position on the scale.

How to Use a Current Meter

If we wish to measure the current flowing in a circuit, the current meter (ammeter or milliammeter) should be connected in *series* with the circuit. This is illustrated in Figure 8. If we wish to measure the current flowing in the circuit consisting of the battery and resistor shown in Figure 8(a), the circuit should be broken and the meter inserted in series with the circuit. Two methods of doing this are illustrated in Figure 8(b) and 8(c). In either case we would obtain the same reading on the meter. Figure 8 also indicates the proper way to connect a meter regarding polarity. The (+) terminal of the meter should be connected to the side of the circuit which connects to the (+) of the source, and the (-) terminal of the meter should be connected to the side of the circuit which connects to the (-) of the supply.

Two precautions must be observed in using current indicating meters. Current indicating meters (ammeters and milliammeters) should *never be connected across the source of potential*. Currents higher than that for which the meter is designed should never be passed through a meter. The coil of a meter is made of small wire, and if a current greatly in excess of that for which the meter is designed is passed through the coil, it will become hot and the wire will melt, ruining the instrument. Also, a current greatly in excess of the proper full scale current will cause the pointer to swing so hard against the right hand stop (see Figure 4) that the pointer will be bent or broken.

The ideal ammeter should have little or no internal resistance, since it is inserted into the circuit in series, and any resistance it might have will be added to the circuit resistance, reducing the series current flowing in the circuit. For instance, let us take a practical example. Suppose we have a 2 ohm resistor connected across a 2 volt battery, as in Figure 9(a). Ohm's Law tells us that 1 ampere of current will flow in this circuit. $I = \frac{E}{R} = \frac{2}{2} = 1$ amp.

Now suppose we try to measure this current by inserting in the circuit an ammeter which has an internal resistance of 4 ohms, as shown in Figure 9(b). The two resistances (the 2 ohm resistor and the 4 ohm meter) are in series and would add up, giving us a total resistance of 6 ohms in the circuit. This would limit the current flow to 1/3 ampere. $R_T = R_1 + R_2 = 6\ \Omega$ $I = \frac{E}{R} = \frac{2}{6} = \frac{1}{3}$ amp.

The meter would indicate only 1/3 ampere of current flowing in the circuit, when, without the meter in the circuit, as in Figure 9(a), there was 1 ampere of current. This error resulted from the internal resistance of the meter. To eliminate this error, the internal resistance of the meter should be very low. A typical 0 to 5 ampere ammeter has an internal resistance of 0.03588 ohms. If this meter were used to measure the current in the circuit in Figure 9, the current would be just *slightly less* than one ampere, and as far as the reading on the meter could be determined would be one ampere.

The internal resistance of ammeters is usually only a fraction of an ohm, since ammeters are used in low resistance circuits. Milliammeters and microammeters have higher internal resistance because the moving coil is wound of very small wire. The higher internal resistance of these low current meters does not cause an appreciable error in the amount of current which will flow in a circuit when they are added in series, because they are usually used in circuits containing high values of resistance. To illustrate this point, let us assume that we have a circuit similar to the one shown in Figure 9(A), except a 2000 ohm resistor is used in place of the 2 ohm one. The current which would flow would be 1 ma. ($I = \frac{E}{R} = \frac{2}{2000} = .001$ A or 1 ma.). Now let us assume that, as in Figure 9(B), a current meter, for example a 0 - 1 ma. meter, with internal resistance of 100 ohms is added in this circuit. Under these conditions the total circuit resistance will be 2100 ohms. ($R_T = R_1 + R_2 = 2000 + 100 = 2100$). The current which would flow after the meter was added would be .00095 or .95 ma. ($I = \frac{E}{R} = \frac{2}{2100} = .00095$ A or .95 ma.). This value of current, .95 ma., is very close to the 1 ma. which would have been flowing in the circuit if the meter had not been added. Thus, we can say that the addition of the meter to the circuit has not upset the circuit conditions. If this same meter were to be connected in a circuit with a 200 volt supply and a 200,000 ohm resistor, the error which results will be even less.

The internal resistance of some typical current meters are, for a 0-1 ma. meter, 100 ohms, for a 0-500 microammeter, 200 ohms. The internal resistance of meters made by different manufacturers will not be the same. For example, the internal resistance of a 0-1 ma. meter by one manufacturer is 100 ohms, while the internal resistance of a 0-1 ma. meter made by another manufacturer is 70 ohms.

Direct-Current Milliammeters

Direct current milliammeters are of very great importance in electronics and television, because in this field the currents to be measured are often very small. This is particularly true in vacuum-tube circuits.

The ordinary direct-current milliammeter consists essentially of a permanent-magnet moving-coil instrument of the D'Arsonval type. In the more sensitive of these meters (those having full-scale readings of 30 milliamperes or less), the entire current to be measured passes through the moving-coil, and the sensitivity is controlled by the size of the wire and the number of turns. In the larger sizes of these meters (those measuring more than 30 milliamperes), only a part of the current is passed through the movement and the remainder of the current is "shunted", or by-passed, around it. A shunt is merely a resistor of the proper low value placed in parallel with the meter movement. The proper design of these shunts is very important to the radio and television technician, for this knowledge will enable him to use the same basic instrument to measure a wide range of currents.

To understand the action of a shunt resistor, study Figure 10(a).

This circuit consists of a battery, resistor R, two milliammeters M_1 and M_2, and a shunt resistor R_s. Resistor R_s is called a shunt resistor since it is connected in parallel with the meter M_2, and shunts part of the current around M_2. In the circuit, notice that the total current flowing is 10 ma as indicated by M_1. *However, only 1 ma. of current is passing through M_2.* The other 9 ma. of current is being shunted around M_2 by the resistor R_s. To state this in another way; nine times as much current flows through the shunt resistor as through the meter M_2.

Notice that the current flowing through M_1 is 10 ma. while the current flowing through M_2 is only 1 ma. If the combination of R_s and M_2 were to be connected in another circuit, as shown in Figure 10(b), and one ma of current is indicated on the meter, then we would know that the total current flowing in the circuit is 10 ma. (One ma. through M_2 and nine times as much or 9 ma. through the shunt resistor.) M_2 could be a 0 to 1 ma. meter, and used in this fashion, it indicates that 10 ma. of current is flowing in the circuit when it reads 1 ma. The range of the 0 to 1 ma. meter, when used with the shunt resistor R_s, is 0 to 10 ma. If the meter indicates .5 ma. of current, then the total current would be .5 x 10 or 5 ma. Likewise, a reading of .2 ma. indicates a total current of 2 ma. in the circuit under test. A current of .2 ma. flows through the meter and 1.8 ma. flows through R_s.

Let us apply our knowledge of Ohm's Law to find the ohmic value of R_s required to increase the range of the 0 to 1 ma. meter in Figure 10 to a 0 to 10 ma. meter. Let us assume that we know that the internal resistance of M_2 is 100 ohms. Examine Figure 10(a) again. R_s and M_2 are in parallel. The current flowing through M_2 is 1 ma. Its internal resistance is 100 ohms. We can apply Ohm's Law and find the voltage drop across M_2.

$E = I \times R$

$E = .001 \times 100$ (the current through the *meter* times the *meter* resistance.)

$E = .1$ volt

The voltage across the meter is .1 volt. The meter and the shunt resistor are in parallel, therefore, they have the same voltage drop across them. Thus, there is a .1 volt drop across the shunt resistor R_s. Figure 10(a) shows that the current through R_s is 9 ma. when the current through M_2 is 1 ma., so we have all we need to find the resistance of R_s. We know the voltage across it, and the current through it. Let us put these values in Ohm's Law.

$$R_s = \frac{E_s}{I_s} = \frac{.1}{.009}$$ (Remember current must be in amperes, so we change 9 ma to .009 amperes.)

$R_s = 11.1$ ohms.

Thus, we find that if we connect a shunt resistor of 11.1 ohms across the 0 to 1 ma. meter with internal resistance of 100 ohms, we will increase the range of the meter to 0 to 10 ma.

As an esample illustrating the practicality of shunt resistors, suppose we find that we cannot afford to purchase a wide assortment of meters, but decide to purchase a 0 to 1 milliammeter movement and shunt it for the various currents we want to measure. We decide that if we have a meter which, by means of a switching arrangement, has full-scale ranges of 1 ma., 5 ma. and 25 ma., this will be sufficient. Since the greatest sensitivity needed is 1 ma., we should buy a 1 ma. movement and shunt it for the larger current ranges. The milliammeter which we obtain has an internal resistance of 105 ohms, so the problem is to design shunts for the 5 ma. and the 25 ma. ranges.

The first thing to do in any problem of this type is to draw a diagram of the circuit, and indicate on it all the known quantities. This has been done in Figure 11, where I_T is the total full-scale current to be measured, I_M is the full-scale current through the meter (1 ma. for a 1 ma. meter, etc.), and I_S is the current to be by-passed by the shunt. R_M is the meter resistance (in this case, 105 ohms) and R_S is the resistance of the shunt which we want to find. We see that our circuit is a simple parallel resistance circuit, and, for the 5 ma. range, I_T (the total current) would be 5 ma., I_M (the current through the meter) would be 1 ma. and I_S (the current through the shunt) would be the difference between the total current and the current through the meter. In this case I_S would be 4 ma. (5 - 1 = 4).

Since the voltages are the same across each branch of a parallel circuit, if we find the voltage across the meter branch, we will have the voltage across the shunt branch. Ohm's Law says that the voltage is equal to the current (in amperes) times the resistance (in ohms). To find the voltage across the meter, we substitute the known values in this formula.

$E_m = I_m \times R_m$

$E_m = .001 \times 105$ (Remember that only 1 ma. flows through the meter.)

$E_m = 0.105$

The voltage drop across the meter is .105 volt when a full scale current of 1 ma. is flowing through it. The shunt resistor is connected in parallel with the meter, so it has the same voltage drop across it, or .105 volt. We know that the current through the shunt should be 4 ma., or .004 amp.

Since we know the voltage and the current, we can find the resistance.

$$R_S = \frac{E_S}{I_S}$$

$$R_S = \frac{.105}{.004} = 26.25 \text{ ohms.}$$

Therefore, if we placed a resistance of 26.25 ohms in parallel with our 105 ohm, 1 ma. meter, and caused 5 ma. to go through the combination, 1 ma. would go through the meter and 4 ma. would be shunted around it. Likewise, if we caused only half as much current to go through the combination, only half as much current would go through each branch and the meter would read only half-scale. This could be marked 2.5 ma. on the meter scale. If we caused one-fifth as much current to go through the combination, only one-fifth as much current would go through each branch and the meter would read one-fifth scale. This could be marked 1/5 of 5 or 1 ma. on the meter scale, and so on.

We can determine the resistance of the shunt for the 25 ma. range in the same manner. In this case I_T (the total current) would equal 25 ma. and I_S (the current through the shunt) would be 24 ma. since, with the same 1 ma. meter, I_M (the full scale current through the meter) would remain 1 ma. The voltage drop across the meter when full scale current of 1 ma. flows through the meter is the same as in the previous example, since the current and resistance are the same (.105V). The voltage drop across the shunt would still be 0.105 volt. Since the current through the shunt is now 24 ma. or 0.024 ampere, the resistance of the shunt will be $R_s = \frac{E_s}{I_s} = \frac{0.105}{0.024} = 4.375$ ohms.

If we connect a 4.375 ohms resistor in parallel with the meter, there will be a total of 25 ma. of current flowing in the *circuit* when 1 ma. is passing through the *meter*. Therefore, we could put a scale on the meter which reads 25 ma. for full scale deflection; 12.5 ma. for $\frac{1}{2}$ scale deflection, etc.

Of course we do not need a shunt for the 1 ma. range of our meter since we are using a 0 - 1 ma. meter.

By using a switch to connect the shunts across the meter as desired, we have a milliammeter with three ranges; 1 ma., 5 ma., and 25 ma. The complete circuit is shown in Figure 12.

With the switch in Figure 12 in the position shown, the 26.25 ohm shunt is connected in parallel with the meter, and a full scale reading on the meter would indicate 5 ma. of current flowing in the external circuit. When the switch is turned to the 25 ma. position, the 4.375 ohm shunt is connected across the meter, and a full scale deflection on the meter indicates 25 ma. of current flowing in the external circuit. When the switch is turned to the 1 ma. position, there is no shunt across the meter and a full scale reading of the meter would indicate 1 ma. of current flowing in the external circuit. This same method may be used to find the value of the shunt resistors for any meter.

To find the value of shunt resistors, it is only necessary to know the internal resistance of the meter, the full scale current of the meter, and the desired full scale indication.

It is not possible to increase the sensitivity of a meter. For example, it is not possible to shunt a 0 to 1 ma. meter so that a full scale deflection can be obtained with less than one ma. of current flowing in the external circuit. This is because 1 ma. of current must flow through the moving coil to produce the necessary magnetic field to move the pointer to full scale.

We have seen how we could use one milliammeter, and by employing the proper value of shunt resistors use this one meter to read a wide range of currents. It is also possible to use a milliammeter to indicate a wide range of voltage values.

D-C Voltmeters

If we had a 0 to 1 ma. milliammeter with an internal resistance of 100 ohms, the voltage drop across it for full-scale deflection would be E = IR = 0.001 x 100 = 0.100 volt, or 100 millivolts. Such being the case, the scale of the milliammeter could be divided into millivolts instead of milliamperes, and the milliammeter would then become a millivoltmeter. Thus, mechanically and electrically, there is no difference between a millivoltmeter and a milliammeter.

Full scale reading on this meter would be 100 mv, half scale reading 50 mv, one fourth scale reading 25 mv., etc.

We have just seen how a milliammeter could be used to measure small voltages, and was then called a millivoltmeter. In the example given, a voltage of 100 millivolts applied to the meter would cause exactly one milliampere of current to flow through the 100 ohm internal resistance of the instrument. This current meter may be used to measure voltages up to 100 mv. or 1/10 of a volt. An applied voltage of 50 mv. or 1/20 of a volt will cause the current to be only 1/2 of a milliampere, and the meter pointer will only move to the center of the scale. However, the voltages we will wish to measure in most radio and television circuits will be between 1 volt and several thousand volts, so we will need some way to extend the range of this millivoltmeter.

We will first consider how to make this meter read up to 10 volts at maximum deflection. If the meter can be made to do this, we will also be able to read other voltages which are less than 10 volts. Suppose we now connect a resistor in series with the meter as shown in Figure 13. Notice that we connect the resistor in *series* with the meter, rather than in parallel with it as we did in the case of the ammeter. How large should this resistor be, so that when we are measuring a voltage of 10 volts, the meter pointer will move only to its extreme right hand position, but not beyond? For a full scale deflection of the meter, there must be a .1 volt drop across the meter. Since we have 10 volts, the difference, or 9.9 volts, must be dropped in the resistor. Since we are using a 0 to 1 ma. instrument, the current in the circuit must be 1 ma. when the needle shows full-scale deflection. Since the resistor and meter are in series, this 1 ma. of current will also flow through the resistor. The series resistance, R_s, is equal to the voltage dropped in it, divided by the current through it, or $R_s = \frac{E_s}{I_s} = 9.9/0.001 = 9,900$ ohms. The series resistor used with a milliammeter to make a voltmeter is called a *multiplier resistor.*

By connecting a resistor of 9900 ohms in series with the milliammeter, we have made a voltmeter which will indicate that the total voltage applied to the circuit is 10 volts, when the meter pointer moves to a full scale position. Also, a half scale reading of the meter indicates 5 volts applied, and a 1/10 scale reading indicates 1 volt applied. Since a 10,000 ohm resistor will represent an error of only one percent, we would use this size multiplier resistor in a practical circuit.

To provide a *group* of voltage scales, the same procedure of calculation would be employed. For example, for a 50 volt range, the multiplier resistor will be found to be 49,900 ohms. This is calculated in the following manner. The voltage drop across the meter would be 1/10 volt for full-scale deflection. This leaves 49.9 volts to be dropped across the multiplier resistor. The current through the resistor will be 1 ma.

Applying Ohm's Law we have: $R_s = \frac{E_s}{I_s} = \frac{49.9}{0.001} = 49,900$ ohms. In a practical circuit we would use a 50,000 ohm resistor.

For a 100 volt range, the voltage drop across the multiplier resistor would be 99.9 volts. The resistance would be found to be 99,900 ohms ($R = \frac{E}{I} = \frac{99.9}{.001} = 99\ 900$).

For a 500 volt range, we could employ the same method, and find that the proper value of multiplier resistor would be 499,900 ohms. (500,000 would be used.) A selector switch could be used to choose between these various ranges, giving us a circuit as illustrated in Figure 14.

Using the procedure followed above, it is possible to convert any milliammeter to a voltmeter of any desired range higher than that of the instrument alone. We do not have to confine ourselves to a 0 to 1 ma. meter to do this. A 0 to 2 ma. or 0 to 10 ma. meter could be used just as easily as far as our computations are concerned. To illustrate this point, let us find the value of the multiplier resistor required to convert a 2 ma. meter with an internal resistance of 70 ohms into a voltmeter with a full scale reading of 15 volts.

When 2 ma. is flowing through the meter, the pointer will be deflected full scale. The voltage drop across the meter with this current can be found by Ohm's Law. $E_m = I_m \times R_m = .002 \times 70 = 0.140$ volt. This leaves 14.86 volts to be dropped across the multiplier resistor (15 - .14 = 14.86). We know the voltage drop across the multiplier resistor (14.86V) and the current through it (2 ma.). To find the resistance we apply Ohm's Law. $R = \frac{E}{I} = \frac{14.86}{.002} = 7430$ ohms. The circuit is shown in Figure 15.

The sensitivity of a voltmeter is expressed in "ohms per volt" and is equal to the total resistance of the meter and series resistor divided by the number of volts indicated at full-scale deflection. For example, if a 0 to 10 volt voltmeter has a combined resistance of 10,000 ohms, the sensitivity would be 1000 ohms per volt, $(\frac{10,000}{10})$. From Ohm's Law we would find that the instrument requires 1 ma. of current for full scale deflection $(I = \frac{E}{R} = \frac{10}{10,000} = .001$ a.). In a similar manner, if a 0 to 10 volt voltmeter had a total resistance of but 1,000 ohms, the sensitivity would be 100 ohms per volt and it would require 10 ma. to move the needle to full scale deflection. This shows that the higher the resistance of the voltmeter for any given range, the greater the sensitivity. For measuring voltages of circuits where very small currents only can be taken from the circuit, voltmeters having a sensitivity of 20,000 ohms per volt are popular.

In all cases, a voltmeter should be connected *across the source of potential.* One precaution should be observed in using a voltmeter, and that is to make sure that a voltage is never applied which is higher than the full scale voltage of the range in use. For example, if an unknown voltage is to be measured, it is advisable to first use the highest voltmeter scale to find the approximate voltage, and then to use a range which will give a reading near the center of the scale.

When using a voltmeter, the + terminal of the meter should be connected to the + side of the voltage under test, and the - side of the meter to the - side of the applied voltage.

The High Resistance Ohmmeter

A milliammeter may also be used to measure the value in ohms of a resistance. If we were to take the 0 to 1 ma., 100 ohm, milliammeter we have been using and connect it in series with a $4\frac{1}{2}$ volt battery and a 4,400 ohm resistance, we would have the circuit shown in Figure 16. If we ignore the resistance of the wires and the internal resistance of the battery, the total resistance of the circuit will be 4,500 ohms, which is the sum of the meter resistance and the fixed resistor. A $4\frac{1}{2}$ volt battery in this circuit would make the current in this circuit equal to 0.001 ampere or 1 ma., and this current would cause the meter pointer to stop at the extreme right hand position of the scale. $(I = \frac{E}{R} = \frac{4.5}{4500} = .001$ ampere.)

If we were to change the circuit of Figure 16 by breaking the series circuit at some point and putting terminals at each end of the wire at this break, we would have the circuit of Figure 17. We can connect two wires known as "test leads" at these two terminals. If these two terminals were shorted, that is, connected together with a short piece of wire having almost no resistance, the meter pointer will swing to the right end of the scale. Since, for all practical purposes, the wire which is connected between the test lead terminals, has zero resistance, we could mark this point on the extreme right hand end of the scale "0". An ohmmeter scale is shown in Figure 18. Now let us leave these terminals open by removing the shorting piece of wire. Under these conditions we are actually measuring the resistance of the air between the terminals, but since this resistance is very high, running into many millions of ohms, we may consider it infinite (the greatest possible value). The symbol ∞ (an eight lying on its side) represents infinity, and since the pointer in this case will be all the way to the left, its normal position, we can mark this point infinity. (See Figure 18). If, now, we were to measure a resistor having a resistance of exactly 4,500 ohms by connecting it between the terminals of Figure 17, the total series resistance of the circuit would be 9000 ohms. (4500 + 100 + 4400 = 9000). The current would be reduced to just half of its full scale value, or $\frac{1}{2}$ ma. Thus, the .5 ma. point on the meter scale could be marked "4,500 ohms", since the resistance connected *between the test leads* is 4500 ohms. Likewise, if we were to measure the resistance of a 1,000 ohm resistor by placing it between the test leads or terminals, we would have a total circuit series resistance of 5,500 ohms. (The 4,500 ohms of the meter and series resistor plus the 1000 ohm resistor under test.) Since the battery has a voltage of $4\frac{1}{2}$ volts, the current in the circuit and through the meter will be $\frac{4.5}{5,500}$ or 0.00082 amperes or 0.82 ma. We can, therefore, mark 1000 ohms on our meter scale at this point. (Notice that the scale is calibrated in resistance between the test leads.) Any number of other points can be obtained in the same way. Several more points are shown in Figure 18.

An ohmmeter scale is spread out at the right for low resistance values and is very congested at the left for extremely high resistance values. An ohmmeter, such as that of Figure 18, can be used to measure resistances up to about 500,000 ohms; after that the total space of the scale remaining before the infinity mark, is so small that no accurate reading is possible. To read higher resistance values with some degree of accuracy, the meter movement must be very sensitive or else a higher voltage (series battery and fixed series resistor) must be used. For example, an ohmmeter of the type of Figure 17 can be made to read 45,000 ohms in the center (with correspondingly higher readings at the left) if the series resistance is made equal to 45,000 ohms and a 45-volt battery is used.

In most practical ohmmeters, the meter resistance is so low compared to the series resistor, that its value is ignored. Besides, this series resistor is usually made variable in order to permit adjustment to be made for the varying output voltage of the battery due to its age, and then it is easy enough to compensate for the meter resistance.

After the scale of a meter has been calibrated in ohms, it is a very simple matter to read the ohmic value of a resistor directly from the meter scale. All that has to be done is to connect the resistor between the test leads and read the resistance value directly on the calibrated scale. In commercial ohmmeters, the battery, and series resistor (part of which is variable) are located inside the wooden or plastic case.

Multimeters

Since it is possible to use a single milliammeter in conjunction with suitable resistors and batteries, to read current, voltage, and resistance, most test instruments are manufactured as multimeters.

In these multi-meters, some sort of switching arrangement is provided so that the single milliammeter can be used to read several values of current, voltage, and resistance.

Figure 19 shows a multimeter circuit which uses three current ranges similar to Figure 12, the voltmeter section shown in Figure 14, and the ohmmeter shown in Figure 17.

To use this meter to read current, one of the test leads would be connected to the terminal marked "common" and the other test lead connected to the terminal marked "Ma". The desired current range can be selected by turning the current range switch to the desired position.

To use the voltmeter section of this meter, one of the test leads should be connected to the terminal marked "common", and the other to the terminal marked "Volts". The voltage range selector switch is rotated to obtain the desired range. The ma. switch would have to be in the 1 ma. position to use either the voltage or resistance ranges of the meter.

To measure resistance with this meter, one of the test leads should be connected to the terminal marked "common", and the other to the terminal marked "Ohms".

In the meter shown in Figure 19, two rotary selector switches are shown. In many meters, these two switches will be combined, and controlled by one shaft.

Typical Commercial Multimeters

Figure 20 is a photograph of a typical pocket-sized volt-ohm-milliammeter which is almost a necessity for electronic and television service work. A unit similar to this will be supplied you, to build and use throughout this training program. Notice in the illustration, that the meter incorporates scales for reading various values of voltage, current in milliamperes, and resistance in ohms. This meter scale has been re-drawn in Figure 21 for greater clarity. The rotary switch, used for the selection of the scale to be employed, is marked with the multiplication factor and an indication as to whether it is related to voltage, current, or resistance. Let us suppose that we are measuring voltage and our knowledge of the circuit and our previous experience leads us to believe that we might expect to find a d-c voltage of about 45 volts. We would turn the rotary switch to the "75 V. D.C." position and connect the test leads from the two terminals in the meter to the source of voltage. If there is a d-c voltage present which has a value between 0 and 75 volts, the pointer will indicate somewhere on the scale. Our next problem is to read this exact voltage.

The first thing to do is to look at the extreme right row of numbers of the scales of the meter and find the number which goes into 75, once, or ten times, or a hundred times. The number in this case is 75. Read the values indicated by the pointer, by making reference to this middle lower scale (the one that has numbers 0, 25, 50 and 75). Since we have assumed that the voltage we are reading is 45 volts, the meter pointer will stop just to the left of the "50" on the scale. Since this is between "25" and "50", we know that our unknown voltage lies between 25 volts and 50 volts, and also closer to 50 volts than to 25 volts. Notice that there are 10 small marks between 25 and 50. Since this part of the scale represents 25 volts, each of these marks would represent 25/10 or 2.5 volts. If our pointer were to rest on the second mark to the left of the 50 volt mark, we would read this as 45 volts; if it were to rest on the first mark to the left of the 50 volt mark, we would read it as $47\frac{1}{2}$, if it were to rest on the first mark to the right of the 50 volt mark, we would read it as $52\frac{1}{2}$ volts; and so on.

Suppose we wanted to use this meter to check a voltage which was supposed to be about 350 volts d.c. Looking over the positions and ranges available on the rotor switch, we see one marked "300 V. D.C." and one marked "1500 V. D.C.". Obviously the one marked "300 V. D.C." will not be satisfactory, so we turn the switch to the 1500 volt range and connect our test leads to the voltage source. Next we look for the proper set of numbers on the scale, but we do not find a set ending in 1500. However, we do find a set ending in 15 and it is a simple matter to mentally add two zeros to whatever reading we obtain on this scale. Notice that there is a basic difference of 5 volts for each ten divisions, so each division would represent a reading of .5 volts on the 15 volt range and 50 volts on the 1500 volt range. If our unknown voltage source has a voltage of 350 volts, the pointer will stop 3 divisions to the left of the 5 volt mark on the scale, and we would read this as 350 volts.

Notice that if we wish to measure a-c voltages with this multimeter, we would read them on the center scale rather than the lower scale, but everything else would remain the same.

There are two ranges of resistance on this meter, an "R x 1" range, and an "R x 100" range. If we were measuring a 50 ohm resistor, we would turn the switch to the "R x 1" range and touch the test leads together. If the test leads are shorted together, we would, of course, be measuring zero resistance and the meter pointer should read on or near 0, at the extreme right hand side of the top or ohms scale. If the pointer does not stop at exactly zero, we can turn the "adj. ohms" knob below the selector switch until it does, and then our meter will be properly adjusted for resistance readings *on this scale*. In doing this, we vary the size of the series resistor to compensate for the aging of the battery. We can now connect the test leads across the unknown resistor, and if this resistor has a resistance value between 0 and 10,000 ohms, the pointer will indicate this value directly. Notice how hard it is to accurately read the values at the extreme left end of the scale. To read resistances higher than 1,000 ohms (1M), we would probably go to the "R x 100" scale. Again, we would have to "zero" the meter by the "adj. ohms" knob with the test leads shorted before making a reading. Suppose we want to measure a 4,500 ohm resistor. We would zero the meter with the switch in the "R x 100" position and connect the test leads to the resistor. The pointer will stop at the 45 ohm line on the ohms scale of the instrument, and we would multiply this 45 ohms reading by 100 to get the 4,500 ohm, correct reading.

This meter has two d-c milliampere ranges, 0 to 15 ma. and 0 to 150 ma. To read current, the selector switch should be rotated to the desired range and the reading taken using the bottom scale on the meter.

Figure 22 shows the schematic diagram of the meter shown in Figure 20. The symbol marked "rectifier" is the symbol for a device which has the property of changing a-c current to d-c current. We have said that the D'Arsonval instrument will operate only on direct current, so to measure a-c voltages we must change the a-c to d-c. We will study a-c meters in another assignment in this training program.

Summary

This assignment has presented a large amount of information about d-c meters. It has explained the fundamentals of operation of the almost universally used d-c meter- the D'Arsonval type. It has shown that this meter operates on the principle of the opposing forces of two magnetic fields. One of these fields is produced by a permanent magnet and the other field is produced by the current flowing through the turns of wire in a coil which is pivoted between the poles of the permanent magnet.

It has also pointed out that it is possible to use a current meter to indicate higher values of current than that for which it is desinged by using shunt resistors of the proper value connected in parallel with the meter. Likewise, it is possible to use a current meter to read voltage by using a multiplier resistor in series with the meter. Resistance values can be read by using a battery and series resistance in conjunction with the meter.

It has been demonstrated that it is possible to use one meter, in conjunction with a suitable switching arrangement, resistances, and batteries to form a multimeter. Multimeters are sometimes called volt-ohm-milliammeters, since they will perform the functions of each of these meters. Since only one meter movement is used in a multimeter, such an instrument is much cheaper than individual meters for each use would be.

We have also learned to read the scales of a meter and how to estimate the reading if the pointer does not fall directly on a calibrated division, and what scale to use on a multimeter.

Multimeters are used very widely in the testing and repairing of electronic and television equipment, and for this reason, a technician should have a thorough knowledge of the principles of the operation of a multimeter.

In the next assignment, we will study the subject of resistance in detail, and will learn other ways of measuring resistance.

Test Questions

Be sure to number your Answer Sheet Assignment 11.

Place your Name and Associate Number on *every* Answer Sheet.

Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. What are three effects of electricity?
2. What two things do the spiral springs in a D'Arsonval meter do?
3. Should a milliammeter be connected in series with a circuit, or across the voltage source?
4. What will happen if too large a current is passed through the coil of a D'Arsonval type meter?
5. The movement of the pointer in a D'Arsonval meter depends upon the action of two magnetic fields. Where are these two fields obtained?
6. Is the shunt resistor, which is used to increase the current range of a milliammeter, connected in *series* with the meter, or in *parallel* with the meter?
7. Is the voltmeter multiplier resistor, which is used to increase the range of a d-c millivoltmeter, connected in *series* or in *parallel* with the meter?
8. On the type of ohmmeter discussed in this assignment, is the 0 ohms point on the scale at the left end or the right end?
9. If one is to obtain a correct resistance reading, there must be a variable series resistor (zero adjust) in the ohmmeter circuit. Why?
10. Draw the schematic diagrams for the following meters:
    (a) Milliammeter with shunt resistor.
    (b) Voltmeter with multiplier resistor.
    (c) Ohmmeter.

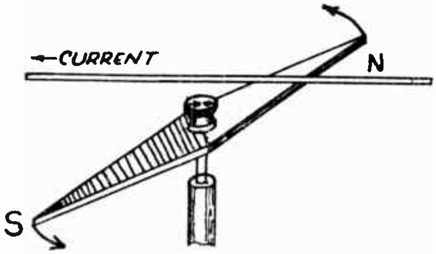


FIGURE 1

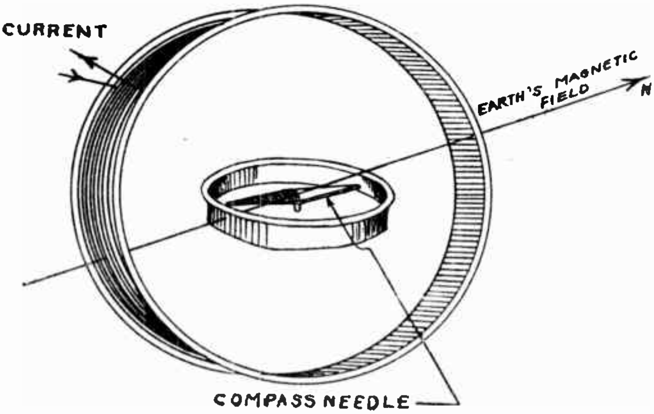


FIGURE 2

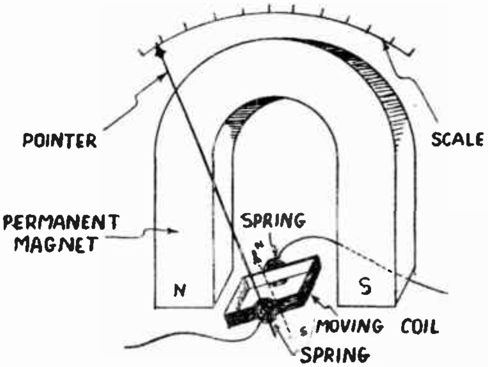


FIGURE 3

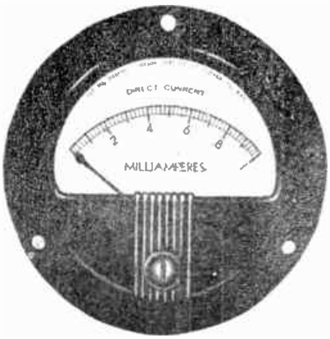


FIGURE 5

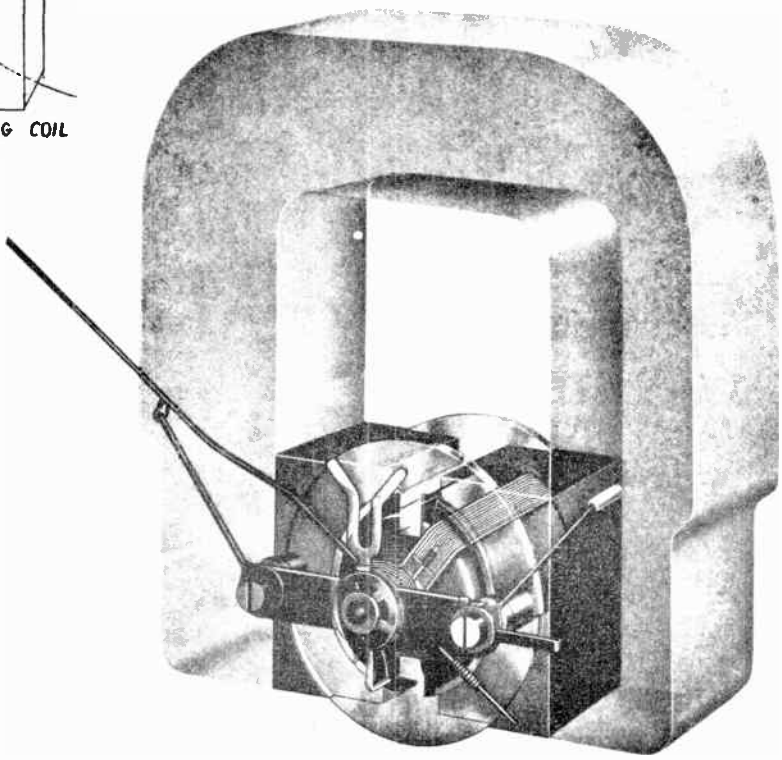


FIGURE 4

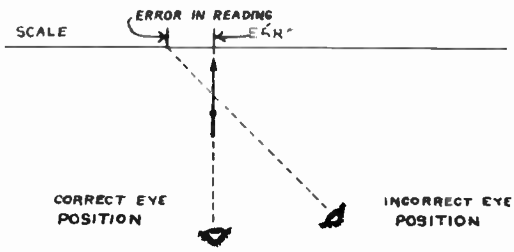


FIGURE 6

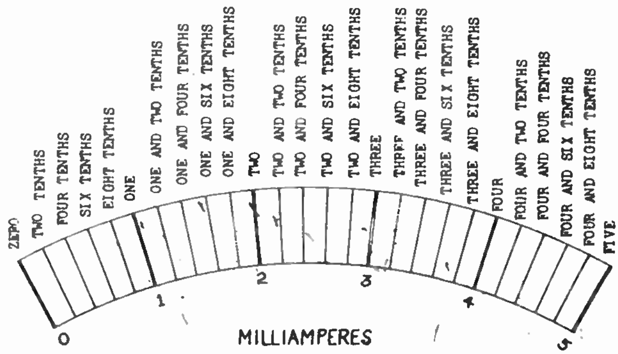


FIGURE 7

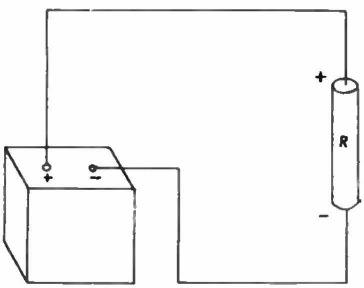


FIGURE 8-A

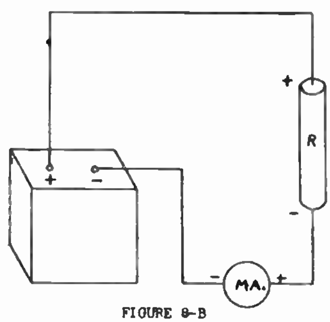


FIGURE 8-B

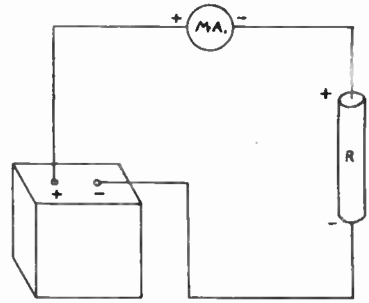


FIGURE 8-C

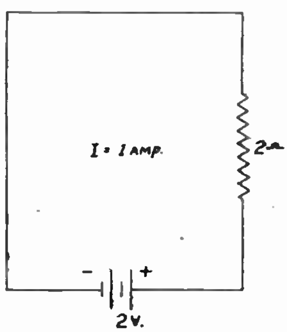


FIGURE 9-A

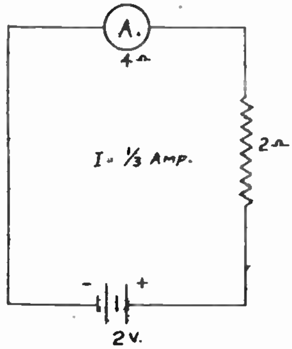


FIGURE 9-B

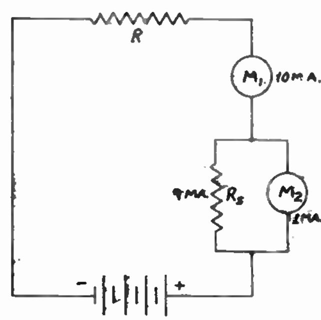


FIGURE 10-A

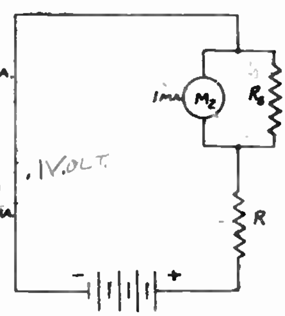


FIGURE 10-B

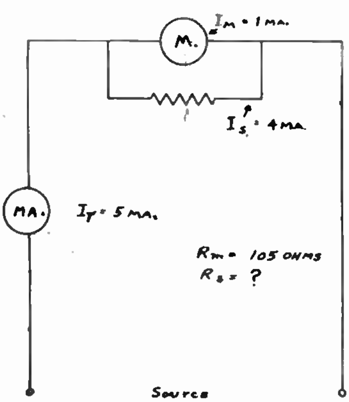


FIGURE 11

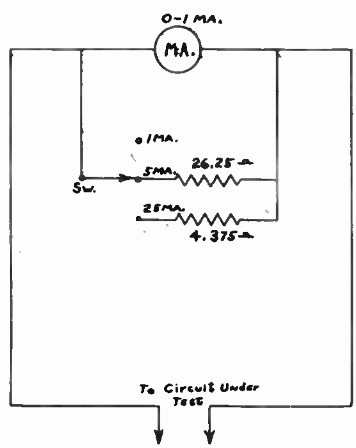


FIGURE 12

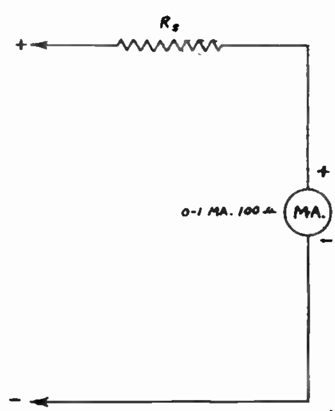


FIGURE 13

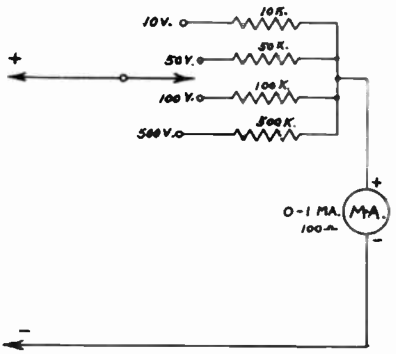


FIGURE 14

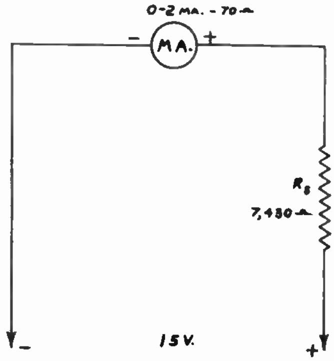


FIGURE 15

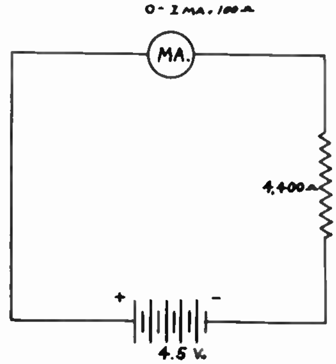


FIGURE 16

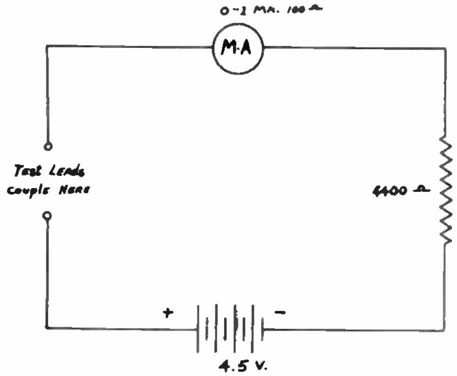


FIGURE 17

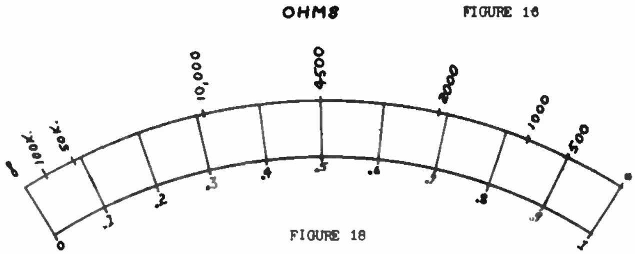


FIGURE 18

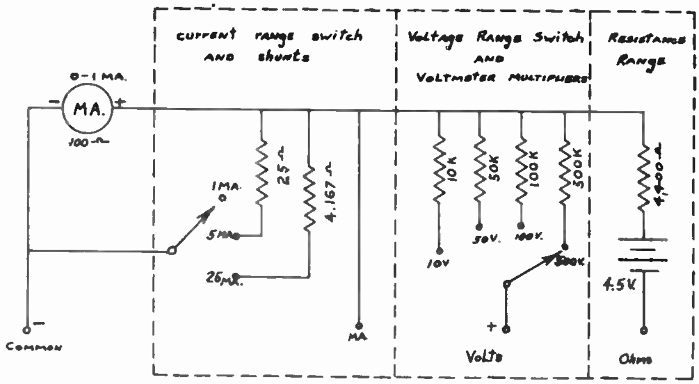


FIGURE 19

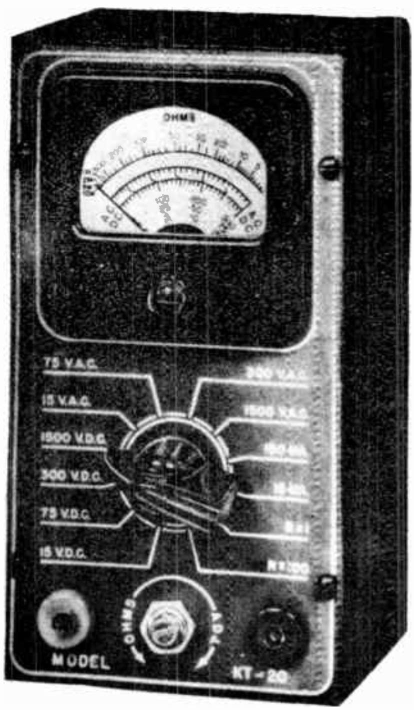


FIGURE 20

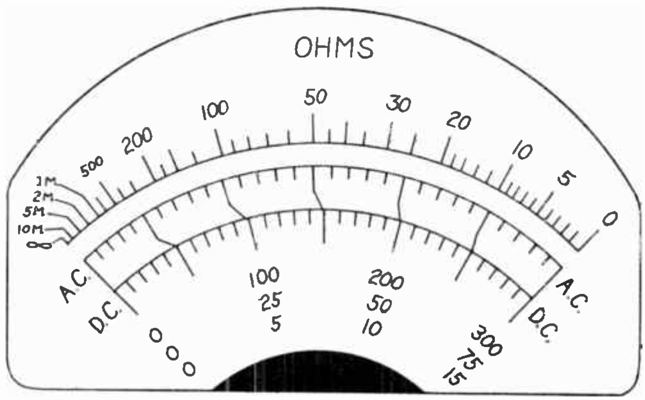
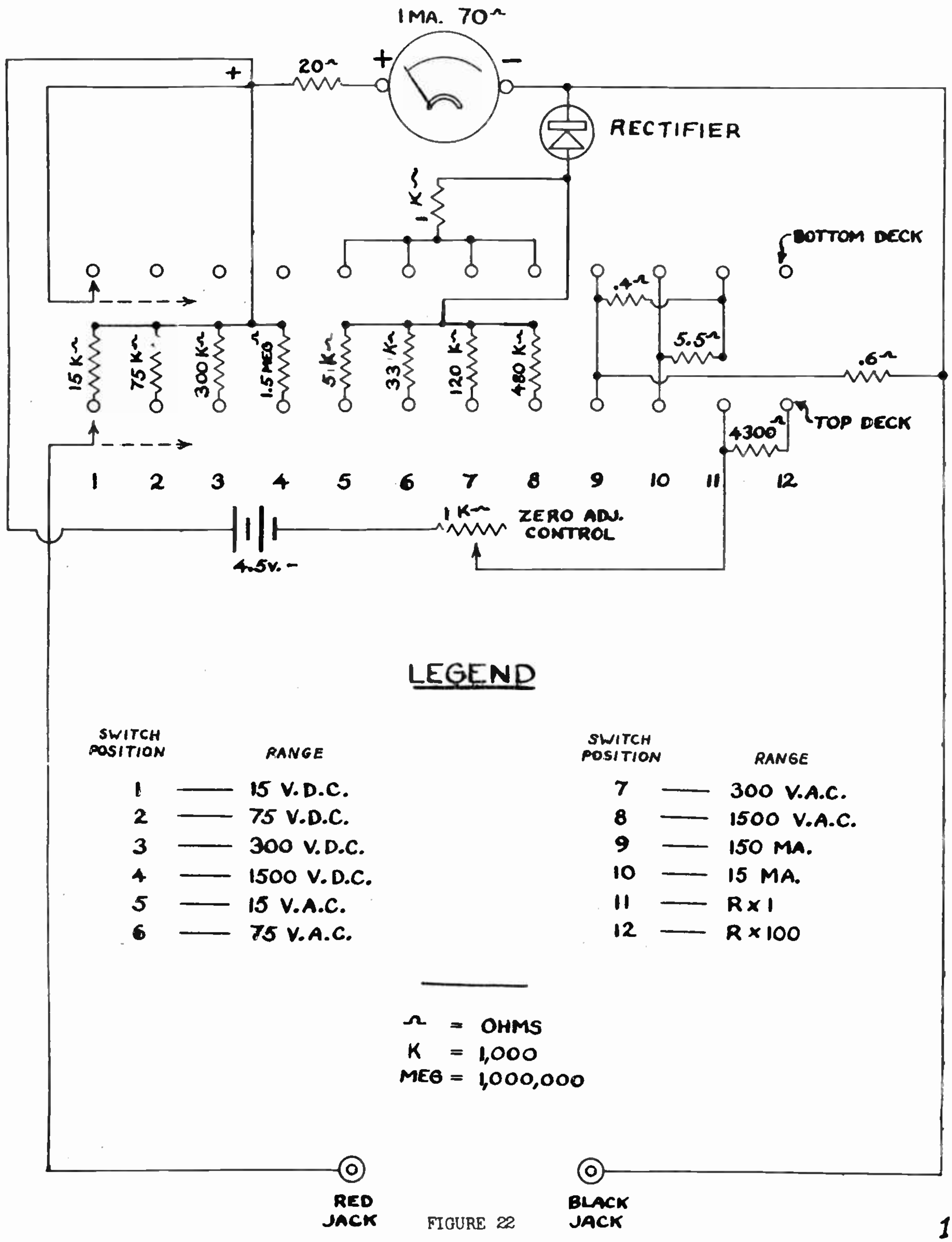


FIGURE 21



LEGEND

SWITCH POSITION	RANGE	SWITCH POSITION	RANGE
1	15 V.D.C.	7	300 V.A.C.
2	75 V.D.C.	8	1500 V.A.C.
3	300 V.D.C.	9	150 MA.
4	1500 V.D.C.	10	15 MA.
5	15 V.A.C.	11	R x 1
6	75 V.A.C.	12	R x 100

Ω = OHMS
K = 1,000
MEG = 1,000,000

FIGURE 22

Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

CONDUCTORS AND RESISTORS **ASSIGNMENT 12**

ASSIGNMENT 12

CONDUCTORS AND RESISTORS

We have seen in the preceeding assignments that even the best electrical conductors, such as silver and copper, have some opposition to the flow of an electric current. This opposition is termed the *resistance* of the component or circuit. It was also pointed out, that there is no clear dividing line between conductors, resistors, and insulators. Of course, conductors will usually be found to have very low resistance; but what might be classed as a resistance in one circuit, might be an insulator in another. For example, it is not at all unusual to find resistors in vacuum tube circuits having a resistance of 10 million ohms; whereas, a component with that high a resistance value would be considered to be an insulator in the commercial power circuits supplying electricity to homes. Thus, conductors, resistors, and insulators differ in degree only; the same basic laws of electric current flow apply to each. It is thought that the atoms of good conductors hold on to their electrons more loosely than the atoms of resistors hold on to their electrons; and the atoms of good insulators hold on to their electrons very tightly. This will account, at least in an elementary way, for the low resistance of conductors, the higher resistance of resistors, and the very high resistance of insulators.

Resistance of Wire Conductors

There are several factors which will effect the resistance of a wire conductor. The first of these factors, which we will discuss, is the material of which the wire is composed.

If we wished to use a wire with the smallest possible amount of resistance for a given size and length of wire, we would use wire made of silver. This is because silver is the best conductor of electricity known, and therefore, has the least resistance. Since silver is a rare metal, it is expensive and therefore is rarely used as a conductor. Instead, a compromise between conductivity and expense is affected, and copper is used. Copper is almost as good a conductor as silver, and of course is much cheaper. Copper has other desirable features as far as wire manufacturing is concerned, since it can be "drawn" into the proper size and shape quite easily.

Another material which is sometimes used as a conductor is aluminum. This material is sometimes used because of its lightness in weight.

To compare the conductivity of these three materials, let us assume that we have a piece of silver wire, a piece of copper wire, and a piece of aluminum wire, all of identical size and length. If the piece of silver wire has 1 ohm resistance, we will find that the piece of copper wire will have approximately 1.06 ohms of resistance, and the piece of aluminum wire will have 1.75 ohms of resistance.

Another factor which effects the resistance of a piece of wire is the length of the wire.

If a piece of wire has some definite resistance, it stands to reason that a piece of the same wire twice as long, should have twice as much resistance. A piece of wire may be compared to a water pipe. Any pipe has opposition to the passage of water, but if the pipe should be twice as long, this opposition will be doubled. If a piece of wire one foot long has one ohm resistance, then 1000 feet of this same wire will have 1000 ohms of resistance.

Another factor which affects the resistance of a wire is its cross-sectional area. If you cut a piece of wire with a sharp tool, and looked at it "end-on", you would see a cross-section of the wire. Since most wire is round, the cross-section of the wire will be a circle. It can be seen easily, that if the area of this cross-section is increased, a larger path will be provided for the movement of the electrons which make up the electric current. In other words, the larger the wire, the less the resistance. The cross-sectional area is proportional to the *square* of the diameter of the wire. Thus, if we double the diameter of a wire, the cross-sectional area will be increased *four* times, and the resistance will be one fourth.

Another factor which affects the resistance of a conductor is the temperature. All *pure metals* will *increase in resistance* as the temperature of the metal increases. This property is called *positive temperature coefficient.* In metals, this increase in resistance is about .4% per degree centigrade increase in temperature. For example, if the resistance of the filament of a light bulb is 20 ohms, when the bulb is not lighted, this resistance will increase to perhaps as much as 40 ohms, when this filament is connected to an electrical circuit and heated to incandescence.

Carbon, which is not a metal, has a negative temperature coefficient. That is, as the temperature increases, its resistance decreases.

Thus, we see that there are four factors which affect the resistance of a conductor, namely; material, length, cross-sectional area, and temperature.

Wire Sizes

We would find it rather inconvenient to say that we were using a wire with a diameter of 403 ten thousandths of an inch, or 3196 hundred thousandths of an inch. For this reason, wire sizes have been assigned numbers.

There have been quite a few different systems for numbering wire, but the Brown and Sharp (B & S) Gauge is the most common one in use in this country and will be the one discussed here.

The Copper Wire Table at the end of this assignment will give you all the information you will ever need about the various sizes of wire which are in common use. Notice that there are eight columns, the first one at the left being marked "Gauge No." This is the number we mean when we talk about a number 20 or a number 36 wire. These numbers start at 0000 and end at 40, the larger the number, the smaller the wire. The second column from the left is the diameter in mils, which is the diameter of the wire in thousandths of an inch. This term "mils" is easy to remember, since it stands for milli-inch, which we know would mean thousandths of an inch. It is much simpler to say that a wire, No. 20 for example, has a diameter of 31.96 mils, than to say it is 31.96 thousandths of an inch in diameter.

The next column gives the cross-sectional area of the wire in circular mils. This is obtained by merely squaring the diameter in mils.

The fourth column shows the weight in pounds per 1,000 feet of the wire, without insulation.

The fifth column is very much like the fourth, but is turned around and gives the number of feet in a pound of the bare wire.

The last three columns list the resistance of the various sizes of pure copper wire in number of "Ohms per Foot", number of "Feet per Ohm", and number of "Ohms per Pound".

To use the wire table, you read down the left hand column to the size or gauge number you are interested in, and then read across to the right to determine the proper value. For example, suppose we wanted to find the resistance per foot of B & S Gauge No. 18 hook up wire. This is usually called "Number 18". Going down the left hand column to 18, and reading across to the proper column, we learn that it has a resistance of 0.006374 ohms per foot. We could also determine that this wire has a diameter of 40.3 mils, a cross-sectional area of 1624 circular mills, weighs 4.92 pounds per 1000 feet, and it would take nearly 157 feet of it to have a resistance of 1 ohm. A table of this type eliminates all calculations and makes available all of the commonly used information for the ordinary sizes of copper wire.

There are many different uses for such a table. For example, suppose you had a roll of wire and wanted to know how many feet of wire it contained. It would be quite a job to unroll it and measure it. Instead, you could weight it, and then, turning to the table, determine the number of feet per pound for this size wire. All you need do then, is to multiply this number by the weight of the roll of wire, and you would have a very close approximation of its length.

Suppose someone asked you how many number 24 wires it takes to equal one number 9 wire. You can use the table to determine the circular mil cross-sectional area of the number 9 wire, which is 13,090. Then doing the same thing for the number 24 wire, we have 404. Dividing 13,090 by 404 gives 32 and a fraction. Thus, approximately thirty two No. 24 wires would be needed to replace one No. 9 wire.

Possibly, you are wondering how wire can be measured accurately when there is but a few thousandths of an inch difference in the diameter of various sizes. This is usually done with a wire gauge. These wire gauges are made in two popular designs. One is circular in shape and has a ring of holes drilled around the outside. The size of each hole corresponds to a wire gauge number. To measure a piece of wire with this gauge, you remove the insulation, and then find the smallest hole the wire will go through. The number corresponding to this hole is the wire size.

The other type of wire gauge has a "V" shaped slot in it and at the proper place on the "V", the sizes are marked. With this gauge, the bare wire is pulled down in the slot as far as it will go without forcing it, and the mark nearest it will give the size of the wire.

Stranded Wires

The B & S Wire Gauge applies to solid copper wires which, in general, are used for all permanent circuits. Solid copper, especially in the larger sizes, is not very flexible, so when it is desired to use the conductor in portable or moveable circuits, some other type of wire must be used. In order to obtain the necessary flexibility, yet have a proper size wire to carry the current, it is customary to make up a conductor of a number of smaller solid copper wires. These smaller size wires are more flexible and by combining a sufficient number of them into a cable, the resistance will be low. This is known as a *stranded* wire.

These smaller wires are twisted together, somewhat like the threads in a piece of string, and therefore, each will carry a part of the total current in the circuit in which they are connected. For example, the attachment cord for the average radio receiver is called a No. 18 stranded wire, although it is actually made of sixteen No. 30 copper wires to provide the necessary flexibility.

By referring to the wire table, you will see that a No. 30 wire has a cross-sectional area of 100.5 circular mils, and that a No. 18 wire has an area of 1624 circular mils. To find the total cross-sectional area of the sixteen No. 30 wires, we multiply 16 times 100.5 and obtain 1608 circular mils. This is very nearly equal to the 1624 circular mil area of the No. 18 wire. Most stranded conductors employ No. 30 wires, and their number is varied to approximate the area of different sizes of solid wire. For example, No. 14 stranded wire is made up of 41, No. 30 wires, and No. 20 stranded wire is made up of 10, No. 30 wires.

For some uses, wire with greater flexibility than that of standard stranded wire is desirable. An example of this would be the wire used for test leads on most test instruments. It is desirable to have this wire very flexible. For this purpose, special flexible wire, Gauge No. 20 is made. This wire is composed of 41 strands of No. 36 wire. *Flexible wire* is made in several sizes for different uses.

Insulation for Wire

In many electronics and television applications, copper wire is wound on forms and spools, to form coils of various sizes and shapes. In most cases, the turns of the coils are wound tightly together and therefore the wire must be insulated. If the different turns actually touch, or make contact with each other, the electrical current would follow the shorter path from one turn to the next instead of passing through the entire length of the wire. Because a condition of this kind provides a shorter path for the current, we call it a "short circuit" or "short"; and to prevent this from happening, we put insulation on the wire.

The insulation on the type of wire used for coil windings is mainly of three materials: Enamel, silk, and cotton. For the first of these, the bare copper wire is run through a bath of special varnish, to apply a thin coat of insulation on its outer surface. This coating is known as "Enamel", and the finished wire as "enameled wire". Enameled wire is used widely in the winding of power transformers, output transformers, etc.

Cotton is a fairly good insulator when dry, and therefore, cotton threads, wound on the outside of a copper wire closely enough to completely cover the outer surface, form a layer of insulation. Wire of this type is known as single cotton covered and often abbreviated as S.C.C. When more insulation is needed, a second layer of cotton is wound over the first layer to produce double cotton covered (D.C.C.) wire. In addition to its own insulating qualities, the cotton helps to keep adjacent wires apart, and thus prevents them from touching.

On the smaller sizes of wire, silk is often used instead of cotton, as it can provide the same insulation in less space. Like the cotton covered wire, we have single silk covered (S.S.C.) and double silk covered (D.S.C.) wire. Cotton, or silk covered wire is used in winding R-F Coils, I-F Transformers, etc.

In addition to these three basic types, we often find wire with a coating of cotton or silk over enamel. These are called cotton enamel (C.E.) or silk enamel (S.E.), whichever the case might be. The enamel is a better insulator than the cotton or silk, but the cotton, or silk, provides the wire with more protection against mechanical injury, and this coating also acts as a spacer between adjacent turns. In general, the insulation of wire used for coil winding is comparatively thin; and, because the wire is usually permanently mounted (as in a coil), the conductors are solid. Wire used for winding coils is often called *magnet* wire.

With the exception of the various types of magnet wire, used in the coils and transformers, most electronics and television work is with conductors that are used to interconnect various circuit components. A great variety of insulation is found on these wires. A few of the more common types will be discussed here.

Perhaps the most widely used type of insulated wire, employed for interconnections in modern electronics and television equipment, is plastic coated wire. This wire is covered with a layer of plastic which has excellent insulating properties.

The type of insulation used often in hook-up wire is push back type. The insulation of this wire is made with a woven cloth which is often either waxed or varnished and which will not unravel. This insulation fits rather loosely and can be pushed back from one end to expose the conductor. Push-back insulation is available on either stranded or solid conductors.

Another type of wire, which is sometimes used for interconnections, uses rubber insulation. This insulation will not push back. Rubber insulated wire will be found on some circuit components, such as filter condensers. In some cases a single layer of cotton insulation is placed directly over the conductor, and the rubber insulation placed on top of this.

Another type of wire, which is used in certain applications in radio and television work, is shielded wire. This wire consists of a conductor, usually stranded, covered with a rubber insulation. The rubber insulation is covered with a woven metallic sleeve which forms a metallic shield. Shielding of this type is used to prevent the conductor from picking up unwanted interference. In some cases, there is a woven cloth, or rubber, covering over the shield to protect it from mechanical damage. Wire of this type is used for the flexible conductor which connects to a microphone and, because it is insulated on both the inside and the outside, the shielding can act as a second conductor as well as a shield.

There are many applications, such as lamps and appliances, when it is necessary to run two conductors from the source of electricity to the unit using it. To take care of the many variations of circuits of this type, a large number of *double conductor* wires and cables are available. Most of these use rubber insulation, or a combination of cloth and rubber insulation. Double conductor wire can also be obtained in a metallic shield.

In certain cases, such as connections from a radio chassis to a loudspeaker, or between two sections in a transmitter, it is often desirable to have three or more wires in one cable. Cables are obtainable with almost any number of conductors and with or without a metallic shield. In these cables, the insulation of the various wires is of different colors, to identify the individual conductors.

There are hundreds of different types of wires, insulations, and cables, but the types discussed will familiarize you with the majority of those found in electronics and television work.

Resistors

Looking at the underside of an electronics or television chassis will quickly convince us that resistors of all types find extensive and extremely important applications in these circuits. As we shall learn later, they may be employed as current limiters, for obtaining bias voltages, for voltage-dropping, for controlling the volume and tone, and for many other uses. They are made in resistance values ranging from a fraction of an ohm to many million ohms, and have an accuracy ranging from less than $\frac{1}{2}$% to as much as plus or minus 20%.

Nearly all resistors in use today may be classified as "wire-wound" or "carbon-composition" type, with the composition type being the cheaper and more common. Carbon is a fair conductor and, therefore, has low resistance. Bakelite and some of the other plastics have a very high resistance. If we were to take powdered carbon and mold it into the shape of the resistors you saw when you examined a radio, we would find that this resistor would have a very low resistance. On the other hand, if we were to do the same thing with powdered bakelite, we would find that this resistor would have a very high resistance. We could mix the two powders in any proportion we wish, and by this means, produce any value of resistance that we wanted. The carbon-composition resistors used in electronics and television are actually made in this fashion, and connecting leads are attached to each end, as shown in Figure 1.

A cross-sectional view of a more modern type of construction of a carbon-composition resistor is shown in Figure 2. In this type of resistor, the carbon-composition element is located inside an insulated tube. By insulating the resistor, it is possible to mount it near metal parts without danger of a short circuit occuring.

Another type of composition resistor is manufactured by the International Resistor Corporation (IRC), and is known as the "metalized" type. The resistors have the carbon mixture baked on a small glass rod which is enclosed in a ceramic insulating material.

Resistor Color Code

In our examination of a radio chassis, we saw that nearly all of the resistors in it had their value indicated by means of a special color coding, rather than by having the actual number of ohms marked on the resistor. This color code has become standard with all the resistor manufacturers and is known as the RETMA Resistor Color Code; RETMA standing for Radio Electronics Television Manufacturer's Association.

The present method of coding resistors consists of painting 3 or 4 bands around the resistor, and closer to one end of it than the other, as shown in Figure 3. Each of these bands represents a number, as shown in the table accompanying Figure 3. To obtain the ohmic value of the resistor, we should first look at the color nearest the end of the resistor - which in this case is Red. We refer to our table and learn that Red represents the number 2, so we write down 2. Next, we go to the second color which is Green, and by referring to the table, we find that this represents five. This gives us 25 so far. Finally, we go to the third color (Yellow) and, by referring to the table, we see that Yellow represents four. However, for the third color we do not add 4 to the other two numbers but, rather, we add *four zeros*. This would make our resistor have the value 250,000 ohms. If there is a fourth color it will be

Silver or Gold and will always represent the tolerance, which will be discussed later.

As another example to illustrate the use of the resistance color code, suppose we have a resistor which has these three bands on it: Orange, Black, and Red. (In each of these examples, the colored band nearest the end will be mentioned first, then the 2nd band and then the third band.) The resistance color code table shows us that the Orange band stands for three, the Black band for zero and the Red band for two, or two zeros in this example, since it is the third color. Combining these figures, we have a value of 3,000 ohms resistance.

Let us take another example. Suppose, we wish to find the ohmic value of a resistor color coded, Gray, Blue, Green, and Gold. From the chart we find:

Gray stands for 8
Blue stands for 6
Green stands for 00000 (not 5, but 5 zeros since it is the third color).
Gold - Tolerance - will be discussed later.

Combining these values, we find the value of the resistor to be 8,600,000 ohms, or 8.6 megohms.

To further demonstrate the use of the resistor color code, we will list the colors of several resistors and the ohmic value directly below each. Check each example against the color code to make sure you understand each.

(1).	Green - Black - Orange			(2).	Violet - Red - Brown		
	5	0	000		7	2	0
(3).	Yellow - Green - Yellow			(4).	Blue - White - Red		
	4	5	0000		6	9	00
(5).	Brown - Black - Brown			(6).	Yellow - Violet - Orange		
	1	0	0		4	7	000
(7).	Green - Gray - Red			(8).	Brown - Black - Green		
	5	8	00		1	0	00000
(9).	Red - Red - Red			(10).	Yellow - Violet - Black		
	2	2	00		4	7	

Notice the ohmic value for the resistor in Example 10. The Yellow and the Violet gave us the 47. The third color is Black. Since the third color tells us how many zeros to add, Black tells us to add 0 zeros or no zeros. Thus, the ohmic value of this resistor is 47 ohms.

For very small values of resistance, the *third* band may be either Silver or Gold. In this case, it represents a decimal multiplier, as shown in the chart. For example, suppose we wish to find the value of a resistor color coded, Orange, Green, Gold.

This Orange and Green, of course, stand for 35, and the Gold as the *third band* stands for a multiplier of .1. Thus, the ohmic value of this resistance is 35 x .1 = 3.5 ohms.

As another example, suppose we wish to find the ohmic value of a resistor color coded Red, Violet, and Silver. The Red and Violet would give us 27, and the Silver, as the *third band*, indicates a multiplier of .01. Thus, the ohmic value of the resistor is 27 x .01 = .27 ohms.

An older method of color-coding carbon resistors did not mark the colors in bands, but rather had the entire resistor body painted one color, a second color splashed on one end, and the third color in the form of a dot somewhere on the resistor. This is shown in Figure 4. These resistors are read in exactly the same way, except that the *Body color is read first*, the *End color second*, and the *Dot tells us the number of zeros to add.* This is easy to remember because the first letter of each word in order spells "BED". The resistor of Figure 4 would have a rated value of 500 ohms.

Suppose you needed to know the value of a resistor which was painted entirely Red. It has a Red body, so the first number is 2; a Red end, so the second number is 2; and a Red dot on a Red body would still look Red, so we would add 2 zeros, making it 2200 ohms.

At this point, it is worth while to go back to the radio we used in Assignment 2, and find the size of each resistor in it. While it is not absolutely necessary to become completely familiar with the Resistor Color Code, all good electronics and television technicians know it by heart, and it is possible that, by not being completely familiar with it, you might brand yourself as an inexperienced or careless worker. If you will practice using this color code, you will soon find that you have memorized the code.

Accuracy of Resistors or Tolerance

One percent of any amount is one one-hundreth of this amount. Ten percent is 10/100 of the amount being considered, and so on. Most commercial carbon resistors are accurate to within plus or minus 10% of the marked or coded value; which means that the resistor may have a resistance value 10% higher or lower than its indicated value and still be within the manufacturers's guarantee. Such resistors have a fourth color painted on them which is Silver. If the fourth color is Gold, the manufacturer has guaranteed that the resistor has an actual value within 5% higher or lower than its marked value. If there is no fourth color on the resistor - that is, there are only three colors - the manufacturer has guaranteed that the resistor will be within plus or minus 20% of its indicated value. Thus, a resistor marked 50,000 ohms with an accuracy of 10% (this is usually called 10% tolerance), may have a value anywhere between 45,000 ohms and 55,000 ohms. However, since the manufacturer has guaranteed that it is between these two values, there is a good chance that it will be quite close to the indicated value. The resistor shown in Figure 3 is within plus or minus 10% of 250,000 ohms, or between 225,000 ohms and 275,000 ohms.

Perhaps you are somewhat surprised that electronics parts can be this much off the required value and yet give good results. Not all electronics equipment circuits permit such variation of resistance values, but carbon resistors are usually employed in those circuits where the resistance value is not so critical. The fact that a piece of equipment is intricate or expensive does not indicate that very accurate resistors are needed. The application of the part itself determines this. For example, if we wished to make a meter accurate to within ½%, the shunts and multipliers would have to be that accurate, whereas, the same instrument using the same circuit, could be made 5% accurate if this accuracy were sufficient for the application. Most ordinary radio equipment is so designed that the resistor values are not critical to within plus or minus 20%.

Carbon-composition resistors are made in several wattage ratings. One-quarter watt, one-half watt, one watt and two watt resistors are the types generally used. The larger the wattage rating, the larger the resistor will be physically. Figure 5 shows the actual size of resistors with these four wattage ratings.

Wire-Wound Resistors

When resistors must handle greater power, or have better accuracy, they are made of a high resistance wire such as nichrome. Commercially, these resistors are made by winding the resistance wire on strips of fiber, or on porcelain tubes. The turns are separated from each other, and the type of resistance wire used, its diameter and total length, determine the resistance of the resistor. These resistors are usually enclosed in a protective coating of baked enamel or special cement which serves to protect the fine resistance wire and prevent resistance change which might occur due to moisture. The majority of these resistors have a metal band around them on which the resistance value is stamped. Figure 6 shows a wire-wound resistor.

Usually, the resistance wire is started and terminated in suitable connector lugs, and sometimes extra connections are made in the middle of the resistor by means of extra terminal lugs. Semi-variable wire-wound resistors have a bare strip along the length, which is not covered with the insulating cement, and permits contact with the resistance wire. Sliding lugs are used to make contact with the wire, and the connections may be adjusted for the resistance value needed. Such a resistor is shown in Figure 7.

Wire-wound resistors are made in resistance values from a fraction of an ohm to about 100,000 ohms, but it is not practical to make these resistors in higher resistance values. They are made in various physical sizes to serve different heat or power dissipating requirements. Wattage ratings from three watts to one hundred watts are common.

Variable Resistors

In many electronics applications, the value of a resistor must be changed for the purpose of adjusting the circuit. We saw in Assignment 2, that when you turn the knob to control the volume of a radio, you are really adjusting a resistor. Some variable resistors are made so that a sliding contact, easily controlled by means of a knob, permits the changing of the resistance value between zero ohms and the maximum resistance incorporated in the resistor. Such units have but two terminals. One terminal is the end connection; the other is the sliding contact. When the slider is near the fixed terminal, the resistance is at a minimum, and as the slide moves away, the amount of resistance between the two terminals increases. These units are called rheostats and are usually made in low resistance values; from a few ohms minimum to several thousand ohms maximum. Figure 8 shows a typical rheostat.

Potentiometers are very similar to rheostats, but have three connecting terminals; both end terminals being used and the arm connected to the third terminal. As the resistance between the arm and one of the fixed terminals is increased, the resistance between the arm and the other fixed terminal is decreased. These two sections of resistance always add up to the total resistance of the potentiometer.

Most potentiometers are mounted on the side of the chassis and require a single 1/2 or 3/8 inch hole. Several makes of potentiometers have an extra rib which requires a small hole beside the larger one. This protruding rib prevents the entire unit from revolving as the shaft is turned. The shafts of potentiometers are supplied quite long and must be cut to size, but since they are made of soft metal, this is easily done with a hack-saw. Sometimes the shaft comes notched in sections, permitting breaking off the extra length with a pair of pliers. More recently, several manufacturers are marketing their potentiometers without shafts; separate shafts of all descriptions being available and quickly installed.

Potentiometers are often called volume controls, since they are used for this purpose in radio receivers. However, this is not a particularily good name, since potentiometers are also used in many other applications such as tone control circuits, oscilloscope, test instruments, etc.

Some potentiometers are made with resistance wire in a manner similar to wire-wound resistors. Wire-wound potentiometers are used primarily where low value resistance units are needed and electrical power is handled by the circuit. A wire-wound potentiometer, with the dust cover removed, is shown in Figure 9.

The maximum values of wire-wound potentiometers are between several ohms and about 20,000 ohms. Potentiometers using a carbon deposit as the resistance element are used more commonly, and are obtainable in resistance values between 1000 ohms and 20 megohms.

In some potentiometers, the arm having the center terminal for its connection is grounded to the shaft and the metal framework of the unit, but in most cases, the elements of the potentiometer are entirely insulated from the metal framework.

It is possible to install an "on-off" switch on the back of most potentiometers, so that the first rotation of the shaft will operate this switch. Figure 10 shows a potentiometer with the switch mounted on it. In most cases, to install the switch, it is only necessary to remove the dust cover, as shown in Figure 9, and install the switch assembly in the place. There is no electrical connection between the switch and the resistance element of the potentiometer.

Connecting the Potentiometer

We have seen that a potentiometer has three terminals, the center terminal being connected to the movable arm. When a potentiometer is to be connected into a circuit, the manner in which the other two terminals are connected in the circuit is important. Let us assume that you are holding a potentiometer in your left hand with the shaft pointing directly at your face, and the connecting terminals at the bottom of the unit. This would appear as in Figure 11. Now turn the shaft all the way to the left; counter-clockwise. There is now almost no resistance between the terminal on the left and the center terminal; but between the right hand terminal and the center terminal there is a maximum resistance. Now as you rotate the shaft to the right, or clockwise, you increase the resistance between the left and the center terminals, and decrease the resistance between the right terminal and the center terminal.

Usually the output of any radio equipment is increased as the control knob (on the shaft of the potentiometer) is turned to the right or clockwise. Consequently, the potentiometer must be connected so that the circuit will be changed to produce an increased output by a clockwise rotation of the slider. You will be able to apply this knowledge when you begin to study actual radio circuits.

Let us now consider what resistance we will get between the left-hand terminal and the center terminal for different positions of rotating arm. If we start with the rotating arm in the extreme counter-clockwise position, we should have about zero resistance. Actually, in high-resistance potentiometers, this minimum resistance may be as much as several hundred ohms, but this is so small compared to the total resistance of the unit, that we may ignore it. Since we have not turned the shaft, we can call this position of the rotating arm 0% of the effective rotation from left to right.

If the potentiometer, we are using for our example, is made up of *a uniform* deposit of resistance-carbon material, at the mid-point of the rotation (corresponding to 50% of the effective rotation) we would have one-half of the total resistance of the unit. We say, then, that this potentiometer has a "linear taper", which means that the resistance between the terminals we are considering varies linearly (directly) with the rotation. At 75% effective rotation, or three-quarters of the way around to the right, we would have three-quarters of the total resistance. Thus, if we are using a potentiometer having a total resistance of 1,000,000 ohms, we would have 750,000 ohms between these terminals.

For most control applications, non-linear taper types of potentiometers are needed. These potentiometers do not have equal resistance changes for equal changes of rotation. In some of these units, the first 50% of rotation brings only a very small change in resistance between a set of terminals, and the bulk of the resistance change occurs at the end of the rotation. In other units, a great deal of resistance change occurs as the rotation is started, but then the change becomes gradual. Figure 11 shows the tapers for a series of potentiometers made by the P.R. Mallory Company. Taper No. 1 has very little resistance change for the first half of the effective rotation, whereas, taper No. 2 has very little resistance change for the last half of the effective rotation. Taper No. 4 is a linear taper.

Servicing Potentiometers

Since the variable resistor used as volume and tone controls receive considerable mechanical wear in addition to the normal component electrical heating, they often wear out or become quite noisy, and thus require replacing or reconditioning.

Of course, there is little that can be done to repair a potentiometer that has become worn out, since this usually means that the resistance element is worn through. It is possible to repair this breakage in a wire-wound control by soldering a small strip of copper or brass foil across the open section, but this procedure is not recommended except in a case of absolute necessity, since, the wearing through of any section indicates that the whole strip is probably badly worn and likely to break in other places. In cases of emergency, it is sometimes possible to patch up a carbon control, until a replacement can be obtained, by rubbing a piece of pencil lead on the worn spot. However, it is never possible to obtain the same taper and total resistance by this method, and the control should be replaced as soon as possible.

One of the most frequent symptoms of trouble in potentiometers, used as volume controls and tone controls, is "noise". When a "noisy" control is turned, a crackling-scratching sound will be heard in the loudspeaker. The cause of the noise is usually an accumulation of oxidized grease or oil on the wiper arm. At the time of assembly of the potentiometer, the manufacturer usually coats the wiper with a type of grease which prevents oxidation of the contact areas. As a rule, this grease coating will maintain its original condition for a period of one or two years, but it eventually becomes hardened and, being a non-conductor, causes the wiper to make a noisy contact. To properly clean the control, the dust cover or switch, whichever is used, should be removed; and, with the control immersed in a grease solvent such as carbon tetrachloride, the control shaft should be rotated through its range several times.

The Measurement of Resistance

In the discussion of the multimeter in Assignment 11, we saw how it is possible to measure resistances with a fair degree of accuracy by properly connecting a milliammeter, a battery, and a resistor in series.

If we attempt to design an ohmmeter, so that a wide range of resistance can be read, we find that the instrument will not be very accurate at the extreme low end or the extreme high end of the scale. The error on the extreme low end is due to the meter movement inaccuracy; the error on the high end of the scale is due to the crowding of the scale. For these reasons, ohmmeters are usually made with more than one range and in several main types. The principal types are: (1) The series ohmmeter, (2) the shunt ohmmeter, and (3) the combination series-shunt ohmmeter. In the series type, the resistance to be measured is connected in series with the meter and the battery; in the shunt type, it is connected in parallel with them; and in the combination type, the circuit is so arranged that it is connected as a series type for the high resistance ranges and as a shunt type for the low resistance ranges - thus using each type of circuit for the resistance range it is best suited to measure.

Figure 12 is the basic circuit of the series type ohmmeter which we studied in the last assignment. R is the zero-resistance current limiting resistor and is made variable, so that when the battery ages and its voltage drops, this resistance can be decreased in order to make the instrument read zero when the test leads are shorted. In many cases, this resistor is composed of a fixed and a variable resistor in series, for in this way, a fine adjustment is obtained with the variable resistor, inasmuch as a given movement of its shaft changes the resistance of the entire circuit by only a small percentage.

Another arrangement for the "zero-ohms" adjusting resistor (R) is shown in Figure 13. Here it is connected in series with a fixed resistor (N) of low resistance, and the two of them together are connected in parallel with the meter. A current limiting resistor (P) is connected in series with the meter and battery. In this case, when the battery ages, the value of R must be increased so that it shunts less current away from the meter, thereby, making it possible to bring the reading up to full-scale value when the test leads are touched together. This latter arrangement is the one most frequently used in commercial instruments, since it provides a greater degree of accuracy, when several resistance ranges are used, than does the arrangement shown in Figure 12.

Let us suppose that the series ohmmeter of Figure 13 will accurately indicate resistances over the range of from 100 to 100,000 ohms. If we wished to use this same instrument to measure resistances over the range of from 1.0 to 1000 ohms, we could connect a shunt resistor (S) of the proper value to shunt the proper amount of current away from the meter circuit as shown in Figure 14.

With this arrangement, when a *small* unknown value of resistance is connected between the test leads, the meter deflection will be much less than in the circuit shown in Figure 13. (Remember that in the circuit shown in Figure 13, if a small resistance is connected between the test leads, the meter deflection will be nearly full scale). Thus, by choosing the correct value of S, it is possible to calibrate a scale for the meter which will accurately indicate small values of resistance. This circuit is an adaptation of the series type of ohmmeter, since the unknown value of resistance is connected in series with the battery and meter.

The Shunt-Type Ohmmeter

The basic circuit of the shunt-type ohmmeter is simply one containing two parallel resistors and having a constant applied voltage. One of these parallel resistors is the meter itself, which will measure the current in that branch. The other branch, which is the unknown resistor, carries the remainder of the full-scale current. Again, in this type of instrument, the meter scale can be calibrated in ohms of resistance rather than in current.

An examination of Figure 15 should help you understand the shunt ohmmeter. Suppose a milliammeter and a battery are connected in series with a current limiting resistor as in (A). Let the internal resistance of the meter be 50 ohms and the battery voltage 3 volts. If the meter has a full-scale reading of 1 ma. (0.001 ampere), then the resistance of the complete circuit must be 3,000 ohms, and the resistance of the variable current-limiting resistor is 2,950 ohms. $(R = \frac{E}{I} = \frac{3}{.001} = 3000\ \Omega.)$

The unknown value of resistance, R_X, is connected in parallel with the meter as shown in Figure 15(B).

Now, suppose that the meter is shunted by a resistor, R_X, of 50 ohms, as in (B) of Figure 15; then if R is 2950 ohms, the total circuit resistance becomes 2950 plus 25 (the equivalent of the 50 ohm resistor and 50 ohm internal resistance of the meter in parallel), or 2975 ohms. The current flowing from the battery will be given by Ohm's Law, or I = E/R = 3/2975, or 0.001008 ampere, or 1.008 ma. This is very nearly the same current as before we added the 50 ohm resistor in parallel with the meter, but the important point is that now only *half* of this current is flowing through the meter, and the other half is flowing through the 50 ohm resistor. Consequently, since the meter will always read 1/2 ma. with a 50 ohm resistor connected between the test leads, we could mark the half-scale point on the scale "50 ohms".

If we replace the 50 ohm resistor at R_X by a 25 ohm resistor, the meter will only take 1/3 of the total series current and will, therefore, read 0.333 ma. This point on the scale could be marked "25 ohms".

If the external resistor, R_X, is made 75 ohms, the current through the meter would be 0.6 ma. and this point on the scale could be marked "75 ohms".

Figure 16 shows a diagram of the scale for this meter. Additional ohms readings have been added to make the scale complete. Examination of Figure 15 will show that when the test leads on this type of ohmmeter are shorted together, there will be a short circuited path directly around the meter, and therefore, no current will flow through the meter. Zero ohms on this meter will be on the *left* end of the scale, as shown in Figure 16.

If there is no resistor connected between the test leads, as in Figure 15(A), there will be one ma., or full scale current, through the meter This is when the only resistance between the test leads is the resistance of the air. Thus, infinity on this ohmmeter is at the right end of the scale. Therefore, the scale on this type of meter has the *low* resistance values at the *left* and the *high* resistance values at the *right*. Compare this meter scale to the scale for the series type ohmmeter in Assignment 11. Notice that this shunt-type ohmmeter will read lower values of resistance, and also, that its scale increases from left to right, which is opposite to the series type of ohmmeter scale.

If Figure 15 is examined, it will be noticed that the meter in the shunt type of ohmmeter is always in series with the battery, whether or not an unknown resistance is being measured. Consequently, we would always have a drain on the battery. To avoid this, this type of ohmmeter should have a switch in series with the meter and the battery, and this switch should be opened when the instrument is not in use.

A number of commercial multimeters use an arrangement whereby a series type ohmmeter is used for high resistance measurements, and a shunt type for low resistance measurements.

The Wheatstone Bridge

The ohmmeters we have described provide a quick easy method of checking resistors, but it is exceedingly difficult to design and build an ohmmeter which will have a consistent accuracy of 5% or better. Consequently, laboratory technicians and engineers, who wish to measure resistances with a high degree of accuracy, resort to a circuit known as the Wheatstone Bridge. Fundamentally, the Wheatstone bridge is a method by which an unknown resistor is compared to a known resistor, and in its simplest form, is shown in Figure 17. The meter of Figure 17 is known as a galvanometer. A galvanometer is nothing more than a very sensitive milliammeter with the pointer so arranged that it indicates in the center of the scale when there is no current through the instrument; it reads to the left when a current passes through the instrument in one direction; and it reads to the right when a current passes through the instrument in the other direction.

Three known resistances (R_1, R_2, R_3), and the unknown resistance (R_x) are connected in the form of a diamond, with a battery connected across the opposite corners of the diamond and a galvanometer connected between the remaining corners. Each resistor is known as an "arm" of the bridge.

To make a measurement, the two "ratio arms", R_1 and R_2, are set at some fixed ratio, usually 1 : 1, 10 : 1, 100 : 1 or 1000 : 1, and allowed to remain that way. The arm, R_3, is adjustable and is ordinarily calibrated directly in ohms. R_x is the unknown resistor to be measured. If we examine Figure 17 carefully, we see that as far as the battery is concerned, the circuit is nothing more than two groups of resistors in parallel, and so if we follow the current from the negative side of the battery through the circuit and back to the positive side, we see that as the current reaches point *a*, it will branch out or split up. Some current will flow through the R_2R_1 branch, and the rest of the current will flow through the R_3R_x branch. These two currents will unite again at the point *c*, and flow back to the battery together.

In order to get a clear picture of how the Wheatstone bridge circuit works, let us draw an analogy from the stream of water shown in Figure 18. We will let *abc* and *adc* be the branches of a stream flowing around an island, I_s. Further, let us imagine that, beginning at the point *d*, a ditch, *g*, is dug across the island. Evidently, if this ditch is joined to the upper branch of the stream at the proper point, there would be no tendency for water to flow in it in either direction. Let us see why this is so. If the end of the ditch marked *b* is connected too far upstream, water would flow in the ditch in the direction from *b* to *d*. If, on the other hand, we were to connect it too far downstream, water would flow in it in the direction from *d* to *b*. There must be, therefore, some point across which we can dig the ditch, so that this point would be neither too far upstream nor downstream, and there would be no flow of water in the ditch in either direction. We all know that water flows from a higher to a lower level, so if we dig the ditch in such a way that both points *d* and *b* are on the same level, no water will flow through it.

This is exactly what happens to the electron current in the Wheatstone bridge. Looking again at Figure 17, let us concern ourself with the adjustable resistor R_3. This arm of the bridge is adjusted until, at some point, there will be no current flowing through the galvanometer. At any other point, the galvanometer will indicate a flow of current in one direction or the other. When there is no current flow in either direction through the galvanometer, we can say that each end of the galvanometer is at the same level of voltage or at the same potential, and at this point, the bridge is said to be "balanced" and the galvanometer is at the "null" point.

If we had chosen R_1 and R_2 to have exactly the same values, then we could immediately tell the value of the unknown resistor by adjusting the bridge for a balance and reading the scale giving the value of R_3. This is so, because when R_1 equals R_2, R_x equals R_3. However, most of the time the values of R_1 and R_2 are not the same, and R_x would therefore, not equal R_3 when the bridge is balanced. In such cases, the ratio of R_1 to R_2 will be the same as the ratio of R_x to R_3. This can be expressed in the formula:

$$\frac{R_1}{R_2} = \frac{R_x}{R_3} \text{ or } R_x = \frac{R_1 \times R_3}{R_2}$$

To illustrate the use of a Wheatstone bridge, let us assume that R_1 is 10,000 ohms, R_2 is 100,000 ohms, and when the bridge is *balanced* (when R_3 is adjusted for a zero reading on the galvanometer), R_3 reads 3376.2 ohms. We wish to know the value of the unknown resistance R_x.

Substituting the known values in the formula, we have:

$$R_x = \frac{R_1 \times R_3}{R_2}$$

$$R_x = \frac{10,000 \times 3376.2}{100,000}$$

$$R_x = \frac{1 \times 3376.2}{10}$$

$$R_x = 337.62 \text{ ohms.}$$

As another example, let us assume that R_1 is 1,000 ohms, R_2 is 100,000 ohms, R_3 is 734.3 ohms when the bridge is balanced. We wish to know the value of the unknown resistance R_x. Substituting the known values in the formula, and solving, we find R_x = 7.343 ohms.

$$R_x = \frac{R_1 \times R_3}{R_2}.$$

$$R_x = \frac{1,000 \times 734.3}{100,000}$$

$$R_x = \frac{1 \times 734.3}{100}$$

$$R_x = 7.343 \text{ ohms.}$$

Figure 19 is a photograph of a good commercial Wheatstone bridge. This Wheatstone bridge, with its self-contained galvanometer and battery, can be used to read resistances from 0.001 to 1,000,000 ohms with an accuracy of ½%.

In this assignment, we have learned a great deal about conductors and resistors. Resistors are perhaps the most numerous of all the components in electronics or television equipment, and resistance is one of the three main properties of any electrical or electronic circuit. For these reasons therefore, this subject will be encountered time and time again in all of our future work. Consequently, you should study this assignment until you are familiar with it, and then review it as often as necessary.

TEST QUESTIONS

Use the enclosed answer sheet to send in your answers to this assignment.

The questions on this test are of the multiple-choice type. In each case four answers will be given, one of which is the correct answer. To indicate your choice of the correct answer, mark out the letter opposite the question number on the answer sheet which corresponds to the correct answer. For example, if you feel that the answer (A) is correct for Question No. 1, indicate your preference on the answer sheet as follows:

1. (X) (B) (C) (D)

Send in your answers to this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. The bands on a carbon resistor are painted Red - Green - Yellow - Silver, in that order. Its ohmic resistance and tolerance is:

   (A) 25,000 ohms, 5% (C) 250,000 ohms, 5%

   (B) 25,000 ohms, 10% (D) 250,000 ohms, 10%

2. The bands on a carbon resistor are painted Yellow - Violet - Orange - Gold, in that order. Its ohmic resistance and tolerance is:

   (A) 47,000 ohms, 5% (C) 470,000 ohms, 5%

   (B) 47,000 ohms, 10% (D) 470,000 ohms, 10%

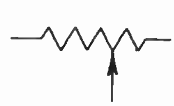
3. The body of a carbon resistor is Green, the end of the resistor is Black, and the dot on the resistor is Red. Its ohmic resistance is:

   (A) 100 ohms (C) 2,000 ohms

   (B) 1,000 ohms (D) 5,000 ohms

4. The symbol for a variable resistor is:

   (A)  (C) 

   (B)  (D) 

5. A No. 8 wire is:

(A) Larger than a No. 18 wire
(B) Smaller than a No. 28 wire
(C) Twice as large as a No. 16 wire
(D) Half as large as a No. 20 wire

6. Copper is:

(A) A poorer conductor than aluminum
(B) A better conductor than aluminum
(C) Equal in conduction to aluminum
(D) A good insulator

7. A spool of wire is marked: No. 22 S.C.C. The S.C.C. means:

(A) Silk and Cotton Covered
(B) Silk and double Cotton Covered
(C) Single Cotton Covered
(D) Silk Covered with Cotton

8. The best wire with which to make ordinary connections between components in a piece of electronic equipment is:

(A) Shielded wire
(B) Rubber insulated wire
(C) Enameled wire
(D) Push-back wire

9. Wire A has a diameter of 1 mil and Wire B has a diameter of 2 mils. Both are copper. The resistance of a 10-foot length of Wire B is:

(A) Greater than the resistance of a 10-foot length of Wire A.
(B) Greater than the resistance of a 15-foot length of Wire A.
(C) The same as the resistance of a 10-foot length of Wire A.
(D) Less than the resistance of a 10-foot length of Wire A.

10. If 500 feet of wire has 2 ohms resistance, what will be the resistance of 250 feet of this same wire?

(A) 1 ohm
(B) 2 ohms
(C) 4 ohms
(D) 250 ohms

B & S GAUGE COPPER WIRE TABLE

Gauge No.	Diam. in Mils.	Area in Circular Mils.	W/c INSULATION Weight in lbs. per 1000 feet	Feet per Pound	Resistance of Pure Copper in Ohms at 68° F. Ohms per Ft.	Feet per Ohm	Ohms per lb.
0000	460.0	211600.	640.5	1.56	.0000489	20440.	.00007639
000	409.6	167800.	508.0	1.97	.0000617	18210.	.0001215
00	364.8	133100.	402.8	2.49	.0000778	12850.	.0001931
0	324.9	105600.	319.5	3.13	.0000981	10190.	.0003071
1	289.3	83690.	253.3	3.95	.0001237	8083.	.0004883
2	257.6	66370.	200.9	4.98	.0001560	6410.	.0007763
3	229.4	52630.	159.3	6.28	.0001967	5084.	.001235
4	204.3	41740.	126.4	7.91	.0002480	4031.	.001963
5	181.9	33100.	100.2	9.98	.0003128	3197.	.003122
6	162.0	26250.	79.46	12.58	.0003944	2535	.004963
7	144.3	20820.	63.02	15.87	.0004973	2011.	.007892
8	128.5	16510.	49.98	20.01	.0006271	1595.	.01255
9	114.4	13090.	39.63	25.23	.0007908	1265.	.01995
10	101.9	10380.	31.43	31.85	.0009972	1003.	.03173
11	90.74	8234.	24.93	40.12	.001257	795.5	.05045
12	80.81	6530.	19.77	50.58	.001586	630.5	.08022
13	71.96	5178.	15.68	63.78	.001999	500.1	.1276
14	64.08	4107.	12.43	80.45	.002521	396.6	.2028
15	57.07	3257.	9.86	101.4	.003179	314.5	.3225
16	50.82	2583.	7.82	127.9	.004009	249.4	.5128
17	45.26	2048.	6.20	161.3	.005055	197.8	.8153
18	40.30	1624.	4.92	203.4	.006374	156.9	1.296
19	35.89	1288.	3.90	256.5	.008038	124.4	2.061
20	31.96	1022.	3.09	323.4	.01014	96.62	3.278
21	28.46	810.1	2.45	407.8	.01278	78.24	5.212
22	25.35	642.6	1.95	514.2	.01612	62.05	8.287
23	22.57	509.5	1.54	648.4	.02032	49.21	13.18
24	20.10	404.0	1.22	617.6	.02563	39.02	20.95
25	17.90	320.4	.97	1031.	.03231	30.95	33.32
26	15.94	254.1	.77	1300.	.04075	24.54	52.97
27	14.20	201.5	.61	1639.	.05138	19.46	84.23
28	12.64	159.8	.48	2067.	.06479	15.43	133.9
29	11.26	126.7	.38	2607.	.08170	12.24	213.0
30	10.03	100.5	.30	3287.	.1030	9.707	338.6
31	8.928	79.71	.24	4145.	.1299	7.698	538.4
32	7.950	63.20	.19	5227.	.1638	6.105	856.2
33	7.080	50.13	.15	6591.	.2066	4.841	1361.
34	6.305	39.75	.12	8311.	.2605	3.839	2165.
35	5.615	31.52	.10	10480.	.3284	3.045	3441.
36	5.000	25.00	.08	13210.	.4142	2.414	5473.
37	4.453	19.83	.06	16660.	.5222	1.915	8702.
38	3.965	15.72	.05	21010.	.6585	1.519	13870.
39	3.531	12.47	.04	26500.	.8304	1.204	22000.
40	3.145	9.89	.03	33410.	1.047	.955	34980.

Figure 19

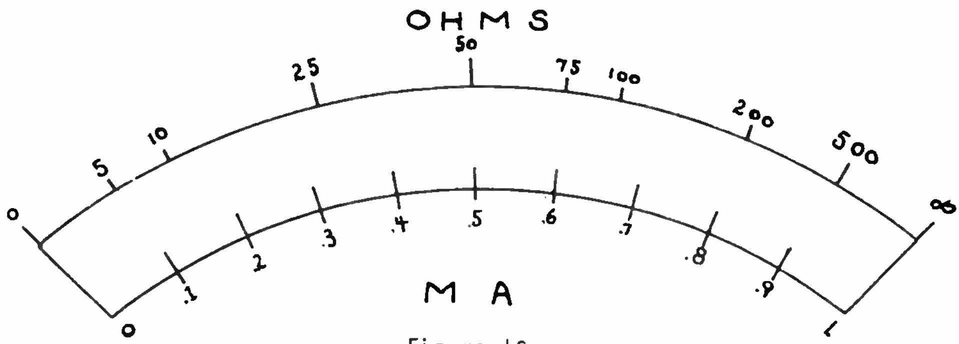


Figure 16

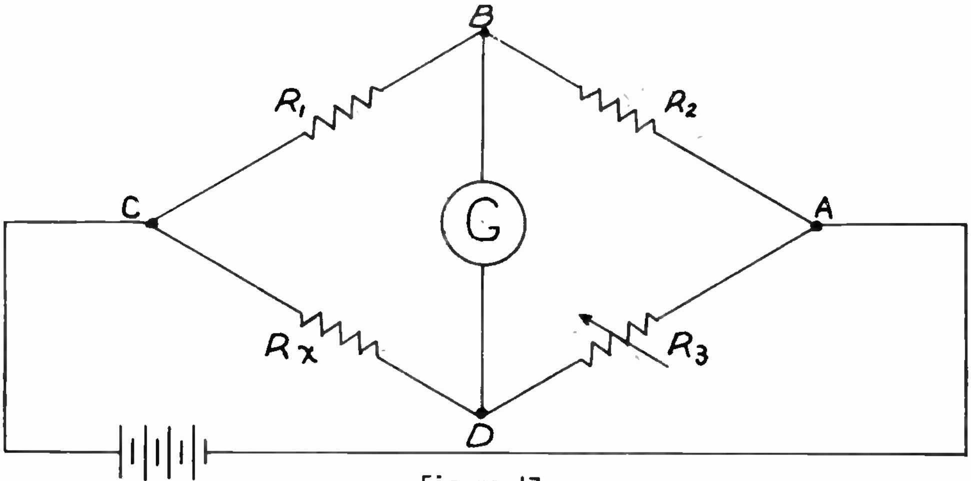


Figure 17

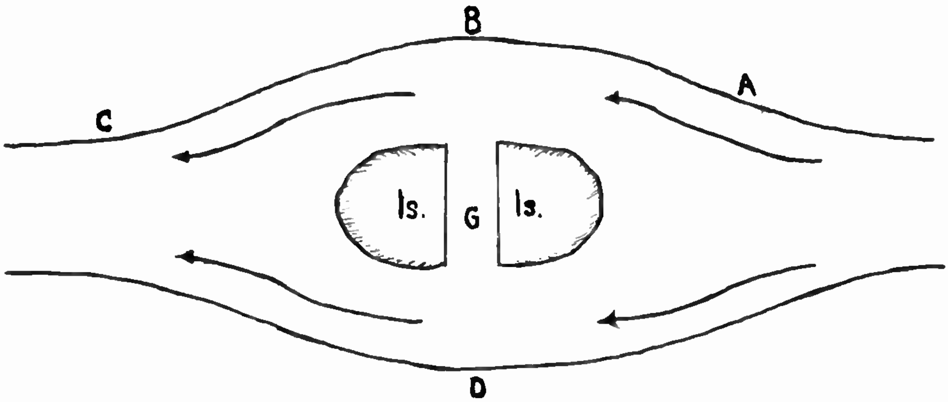


Figure 18

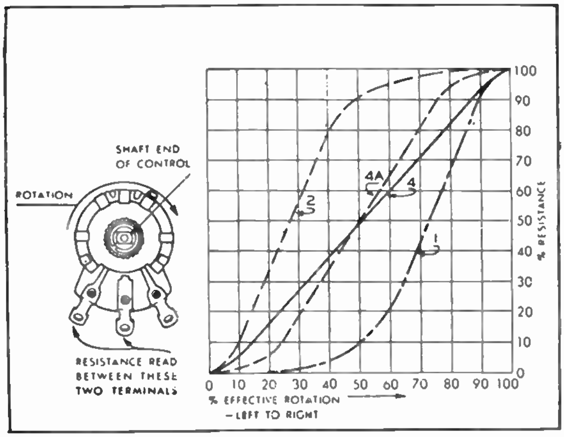


Figure 11

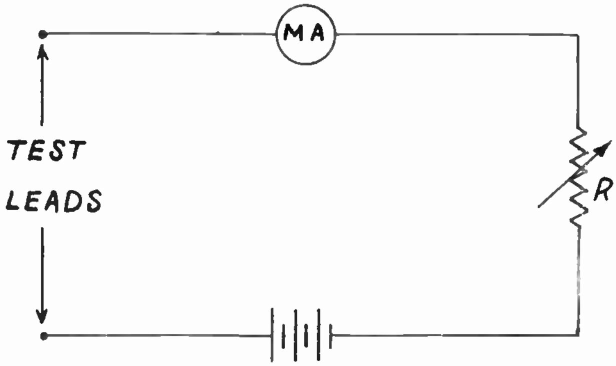


Figure 12

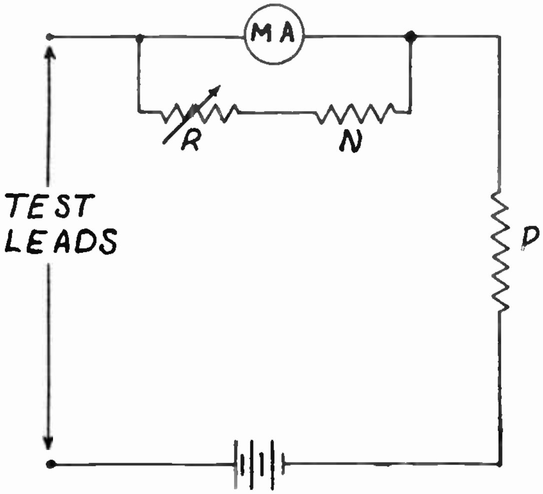


Figure 13

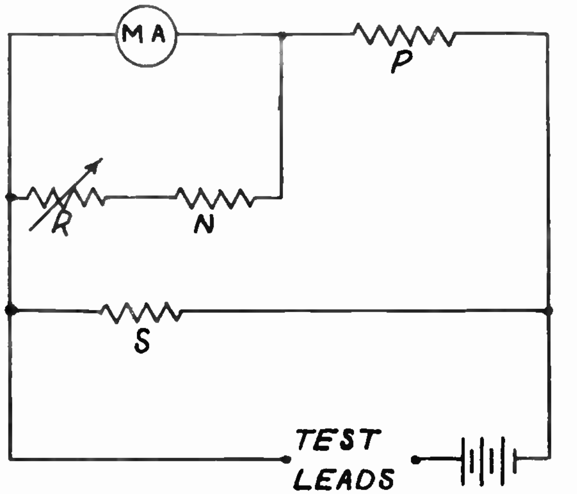


Figure 14

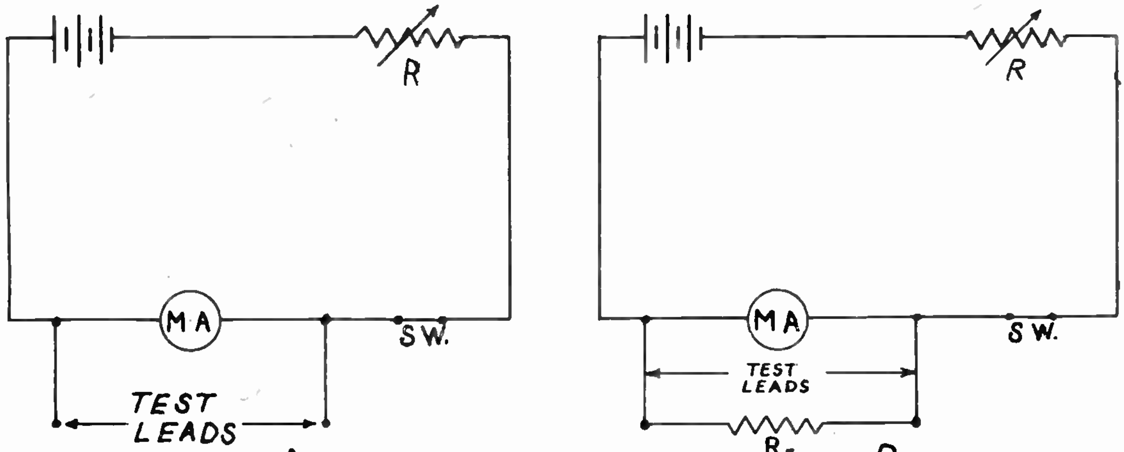


Figure 15

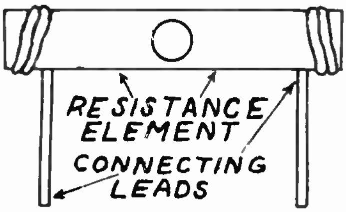


Figure 1

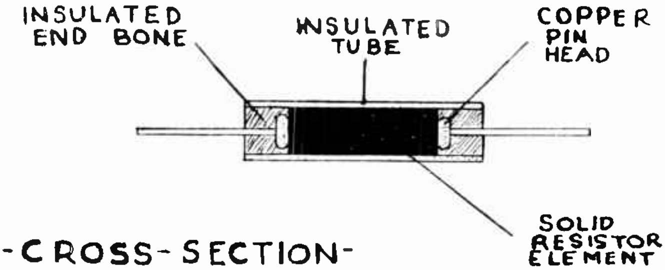


Figure 2

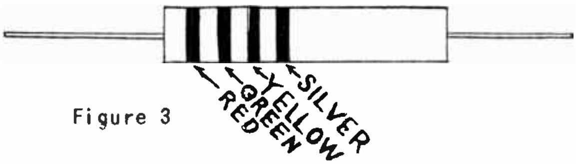


Figure 3

0 BLACK	5 GREEN
1 BROWN	6 BLUE
2 RED	7 VIOLET
3 ORANGE	8 GRAY
4 YELLOW	9 WHITE
Silver as Third Band .01	
Gold as Third Band .1	
Silver as Fourth Band 10%	
Gold as Fourth Band 5%	

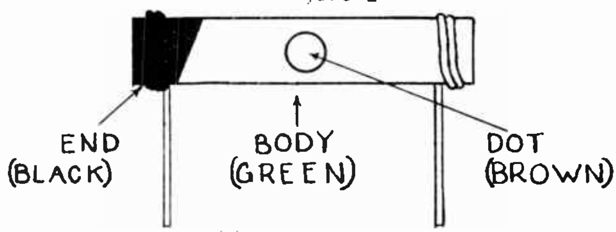


Figure 4

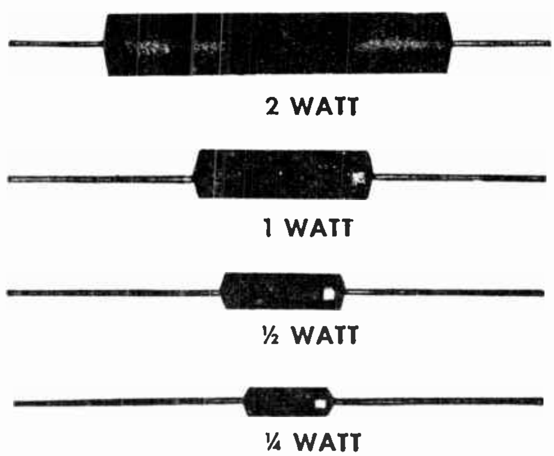


Figure 5

Figure 6

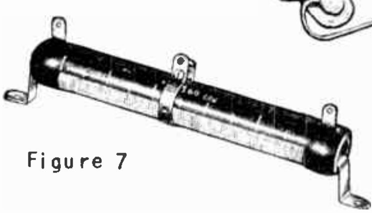


Figure 7

Figure 8

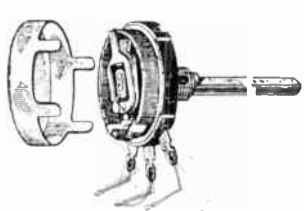


Figure 9

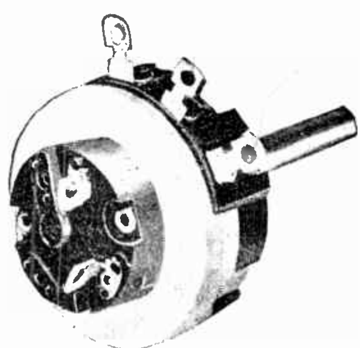


Figure 10

Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

TWO BASIC FORMS OF ELECTRICITY **ASSIGNMENT 13**

ASSIGNMENT 13

TWO BASIC FORMS OF ELECTRICITY

Thus far, in all our discussion of current and voltage, we have dealt with direct currents and voltages, that is, the kind obtained from a battery. The chemical action of a battery is capable of keeping the terminals of the battery at a fixed potential difference, and when a load is connected to it, a steady current flows from the negative terminal of the battery through the load and back to the positive terminal of the battery. This steady current is known as direct current. (There are several abbreviations used to indicate direct current. Some of these are: D-C, D.C., DC, d-c, and d.c.)

The type of d-c circuit which we have been studying, is shown in Figure 1. The battery has a constant emf of 100 volts. The load consists of a 20 ohm resistor. To find the current flowing in this circuit, we may apply Ohm's Law. I = E/R = 100/20 = 5 amperes.

Figure 1(B) is a graph of this current flow, in respect to time. The vertical axis of the graph represents current in amperes, and the horizontal axis represents time in minutes. We see from the graph, that at one minute the current is 5 amperes, at 2 minutes the current is 5 amperes, also at 3 or 4 minutes the current is 5 amperes. This current is, then, a steady, constant value.

Pulsating Direct Current

Strictly speaking, however, a direct current or voltage merely has to act in one direction and may change somewhat in magnitude (amount). It has become common practice to apply the terms *direct current* and *direct voltage* (sometimes *d-c voltage*) to currents and voltages that are essentially constant, and the term *pulsating direct current* to a direct current that acts in one direction but varies somewhat in magnitude over a period of time.

As an example of pulsating direct current, consider the circuit of Figure 2(A). This circuit consists of a 100-volt battery connected to a 20 ohm resistor in series with a rheostat which can have its resistance varied from 0 ohms to 80 ohms. When the resistance of the rheostat is 0 ohms, the current from the battery will be determined by the 20 ohm resistor and will be 5 amperes. With the resistance of the rheostat completely in the circuit, the current from the battery will be determined by the resistance of the fixed resistor, (20 ohms) plus the resistance of the rheostat (80 ohms), or a total resistance of 100 ohms. One ampere of current will flow, as determined by Ohm's Law. I = E/R = 100/100 = 1 ampere.

Now suppose that we were to manually adjust this rheostat so that its resistance varies smoothly from 0 to 80 ohms in just one minute, then immediately begin to reduce this resistance back towards zero, again taking just one minute, then increase the resistance towards its maximum of 80 ohms, and so on. While we are doing this, let us see what is happening to the current flowing from the battery. When the rheostat is set for 0 ohms there will be 5 amperes flowing, and as we start to adjust the rheostat, this current will start to fall off, to 1 ampere, reaching this value one minute later. It will immediately begin to increase again as we decrease the resistance, reaching 5 amperes at the end of the second minute. Then it will begin to decrease to 1 ampere, and so on.

We can plot this information on a graph, putting the current on the vertical axis and time on the horizontal axis, as shown in Figure 2(B). Let us examine this graph. At 0 time, the current is 5 amperes. This decreases to 1 ampere at one minute of time, when the entire rheostat resistance is in the circuit. At 2 minutes the current is 5 amperes again since the rheostat is 0 ohms. At 3 minutes the current has again decreased to 1 ampere, etc. The graph is merely a pictorial representation of the manner in which the current varies over a period of time.

A study of Figure 2(B) will reveal several things: (1) The current does not remain constant, (2) the current never stops or reaches zero, and (3) the current never reverses i's direction, but always flows in the same direction. This is a *direct current* because it always flows in the same direction, but since it varies appreciably in magnitude, it is called a *pulsating direct current* or *pulsating d-c.*

In the early days of commercial electricity, direct currents and voltages were used exclusively because nearly all the electrical power came from storage batteries, which were recharged at intervals by direct current generators. However, it soon became quite evident that it was impossible to send this d-c power over long lines without excessive losses occuring in the lines, especially with more and more electrical current being used. As you know, one formula for electrical power is, $P = I^2R$, making the power loss in the wires increase as the square of the current. Another formula for power is, $P = E \times I$. From this formula we can see, that for a given amount of power, less current will be required if the voltage is increased. To illustrate this, let us assume that 1 kilowatt, or 1000 watts, of electrical power is being used and the voltage is 100 volts. The current will be 10 amperes.

$$P = E \times I$$
$$1000 = 100 \times I$$
$$100I = 1000$$
$$I = 10 \text{ amperes}$$

Now, let us assume that 1 kilowatt of power is to be used, but that the voltage is 1000 volts. The current is 1 ampere.

$$P = E \times I$$
$$1000 = 1000 \times I$$
$$1000I = 1000$$
$$I = 1 \text{ ampere}$$

If the load, in the two preceeding examples, is located at some distance from the source, so that the resistance of the lines is appreciable, say 5 ohms, there will be losses occuring in the lines. The power loss in the lines can be found by the formula, $P = I^2R$.

In the first example the power loss *in the lines* will be 500 watts as shown by the following problem:

$$P = I^2R$$
$$P = (10)^2 \times 5$$

$$P = 100 \times 5 = 500 \text{ watts}$$

In the second example the power loss *in the lines* will be only 5 watts as shown by the following problem:

$$P = I^2R$$
$$P = (1)^2 \times 5$$
$$P = 1 \times 5 = 5 \text{ watts}$$

From these examples we see that the same amount of power (1 kw in this case) can be transmitted from the source to the load with much lower losses occuring, if the voltage is high. Unfortunately, however, there is no simple way to change low d-c voltages into high d-c voltages. For this reason, a different type of electrical current and voltage, known as *alternating current* and *alternating voltage*, was developed. Alternating current is abbreviated several ways. Some of these are: A-C, AC, A.C., a-c, a.c.

Alternating Current

Alternating-current systems began commercially in the United States in 1886. Continued experimentation, investigation, and theoretical analysis have disclosed many merits of a-c systems. The outstanding advantage of the a-c system is the relative ease with which alternating voltages can be generated and transformed in magnitude. For example, it is a very simple matter to change 100 volts a-c into 1000 volts a-c. The result is that, at the present time, approximately 95 per cent of the electrical energy consumed in the United States is generated, transmitted, and actually utilized in the form of alternating current.

In the normal a-c power distribution system, the a-c voltage is developed by huge a-c generators or dynamos, which are driven by waterpower or steam. The output voltage of these generators is high, about 13,000 volts or greater, but if the electrical energy was transmitted at this voltage, the line losses would be high due to the large amount of power handled. For this reason, this high a-c voltage is fed to large transformers. These transformers increase the voltage to a much greater value, in the order of 150,000 volts. This high a-c voltage is then transmitted over the high-tension transmission lines, for distances ranging up to hundreds of miles in some cases. At this very high voltage, the current will be low for a given amount of power, so that the line losses are low.

Of course, this extremely high voltage can not be used safely in homes, so it must be lowered to some safer value, usually 110 volts before it is brought to the homes of the consumers. This is also done by transformers. Transformers perform this operation, changing low values of a-c voltage into high values of a-c voltage, or vice versa, very efficiently, and for this reason, cost very little to operate. Transformers *cannot* be used with d-c, and no other means of transforming the low values of d-c voltage into high values, in an efficient manner has been developed. For this reason a-c is used almost exclusively as mentioned previously.

In future assignments, we will learn that we must change the a-c voltage from the power line into d-c voltage for operation of the vacuum tubes of electronic and television circuits. This is performed by circuits known as rectifier circuits. We shall also learn that when we apply this d-c voltage to certain types of vacuum tube circuits, these circuits will generate an a-c voltage. This type of circuit is called an oscillator. Each of these circuits will be studied in detail at a later date.

By definition, *alternating current (a-c) is a current that periodically changes in magnitude and direction.* Figure 3(A) shows a diagram of a circuit that can be used to produce an alternating current. When switch (S) is in position 1, point X will be 45V positive with respect to point Y. When the switch is in position 2, point X will be 45V negative with respect to point Y. Study the circuit of Figure 3(A) and visualize these results. Figure 3(B) is a graph with the voltage at point X with respect to point Y plotted on the vertical axis. The voltage (E) will have the square wave form shown on the graph if the double throw switch is alternately held in each position for one second. This is an alternating voltage (abbreviated a-c voltage). An alternating current will flow through the resistor connected between points X and Y. This current fits the definition of a-c. It *periodically changes in magnitude and direction.*

Let us study Figure 3(A) carefully to see just what happens. When the switch is in position 1, current will flow from the negative terminal of the battery to point Y, through the load resistor from point Y to point X, back to the battery. When the switch is thrown from position 1 to position 2, the current flow in this direction stops and now the current flows through the load resistor from point X to point Y. If we continue throwing the switch from position 1 to position 2 and then from 2 to 1 at one second intervals, there will be an alternating voltage across the load resistor. This is shown by the graph in Figure 3(B). The current through the load resistor will be reversing itself at one second intervals.

The a-c voltage which is generated commercially differs considerably from the a-c voltage illustrated in Figure 3(B). The most common type of a-c and the type most practical to generate is called a *sine wave* voltage.

The Sine Wave

The graph of a sine wave is shown in Figure 4. The voltage is plotted on the vertical axis and the time in seconds is plotted on the horizontal axis. This voltage is changing in magnitude and direction so it fits the definition of a-c , but its change is more gradual than that of Figure 3(B). Let us examine the graph of the a-c voltage shown in Figure 4 very carefully and see what we can learn from this graph. At 0 time, the voltage is 0. At a short time later (1/240 second) the voltage has increased to +100 volts. Then it gradually decreases until, at 1/120 of a second, the voltage has again reached zero. Now the voltage begins to build up in the negative direction, until at 1/80 of a second, the voltage has reached a maximum value of -100 volts. In the interval of time from 1/80 to 1/60 of a second, the voltage decreases to 0 volts. This is one cycle of the a-c voltage. By definition, *a cycle is one complete succession of events.* A cycle of the seasons, for example, would be from spring to summer, summer to fall, fall to winter, and winter back to spring again. Applied to a-c, this means a voltage or current starts at one value, and goes through all of its variation and returns to that value to complete one cycle. In Figure 4, in the 1/60 of a second, from time 1/60 to 1/30 of a second on the time axis, another complete cycle occurs. Notice that each of the cycles occurs in 1/60 of a second. This a-c voltage is called a 60 cycle a-c voltage, meaning 60 cycles per second. Notice that when we defined a cycle, we did not say when that cycle should begin. Going back to the seasons we could have started our cycle with fall just as easily, and in this case the complete cycle would end with the following summer. In an a-c wave, we can start our cycle anywhere on the sine wave, in which case it would end the next time a similar point on the curve appears.

Another term which is used in connection with a-c is *alternation*. An alternation is one half of a cycle. In the graph of the sine wave in Figure 4, that portion of the sine wave from 0 to 1/120 of a second is one alternation, and is called the positive alternation, since the voltage is positive during this period. The portion of the wave from 1/120 of a second to 1/60 of a second is the negative alternation.

Another term which is used in connection with a-c voltages is *frequency*. Frequency means the number of times anything happens in a given period of time. For example, if a wheel is rotating at a speed of 100 revolutions per second, its *frequency* is 100 rotations per second. Applied to an a-c voltage, the frequency represents the number of cycles which occur in one second. The frequency of the wave shown in Figure 4 is 60 cycles per second. In quite a few cases, the frequency will be called just 60 cycles. The *per second* is understood when dealing with electrical waves.

The alternating current supplied to most of the houses in this country has a frequency of 60 cycles per second. This means that the current and voltage go through 60 complete cycles (remember that this is actually 120 reversals or "alternations") in each second. Those frequencies which are used on power or lighting circuits (25, 50 and 60 cycles per second) are often called the "commercial frequencies".

The frequency of an a-c voltage is very important. To illustrate this, consider Figure 5. The symbol at the left of Figure 5 represents a sine wave generator. This generator could be an a-c generator in a power plant or in a vacuum tube oscillator circuit. The generator is connected to a loudspeaker. If the frequency of the a-c voltage is 60 cycles, the sound waves coming from the loudspeaker will be a very low pitched humming sound. As the frequency of the a-c voltage is increased, (the number of cycles per second becomes higher) the pitch of the note heard in the loudspeaker will become higher. At a frequency of 1000 cycles per second, the note will be a pleasant, low pitched whistle. As the frequency is increased more and more, the note will become higher and higher in pitch, until at about 20,000 cycles per second it has become so high pitched that it cannot be heard. The normal human ear can hear notes ranging from about 20 cycles per second (abbreviated 20 cps) to about 20,000 cps. These frequencies (20-20,000 cps) are called the *Audio Frequencies*, since they are audible to the human ear.

Electrical voltages, corresponding in frequency to the Audio Frequencies are called Audio Frequency voltages, or Audio Frequency signals. The abbreviation for Audio Frequency is AF.

Electrical voltages, whose frequencies are higher than 20,000 cps are called Radio Frequencies (abbreviated RF). Since these signals range in the thousands and millions of cycles, they are usually expressed in kilocycles or megacycles. Radio waves range from 20kc (kilocycles) to several thousand megacycles.

The Radio Frequency signals are generated by vacuum tube oscillators, since the rotary generators, such as used in power plants, cannot be made to produce these high frequencies. The RF signals generated by the oscillator circuit in a broadcast transmitter will be somewhere between 500 kc and 1500 kc, the exact frequency being specified by the Federal Communications Commission. A short wave transmitter may have the frequency of 14,000 kc or 14 mc. It is the fact that different radio stations use RF signals of different frequencies that makes "tuning" of a desired station possible.

The "period" of the wave is defined as the time required for one cycle to occur. For example, if the frequency of an alternating current is 60 cycles per second, each individual cycle would last for a period of one one-sixtieth of a second. We can say that the period is always equal to one divided by the frequency, and we can write this as:

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

where t represents the period and f represents the frequency. If the frequency is measured in cycles per second, the period will be measured in seconds; if the frequency is measured in cycles per minute the period will be measured in minutes, and so on.

The Alternating Current

In our study of direct current theory we learned that potential difference, or a voltage, causes a current to flow through the circuit. This also holds true for alternating current circuits, such as Figure 6(A). During the time the lower terminal of the generator oscillator is negative, an electron current will flow to the right in the lower wire, up through the resistor, and to the left in the upper wire back to the oscillator. A moment later, when the voltage of the oscillator reverses its polarity, the lower terminal will become positive (making the upper terminal negative) and the electron current will be reversed. That is, the current will flow to the right in the upper wire, down through the resistor, and to the left in the lower wire back to the oscillator.

In direct current circuits, an individual electron does not necessarily have to travel completely around the circuit. You will remember that an electron current consists of a large number of electrons slowly drifting around the circuit. Of course, if we were to wait long enough, an electron leaving the battery will return to it, but suppose that there was a switch in the circuit and we were able to close this switch for only one one-millionth of a second. An electron current would flow for this one one-millionth of a second, but this current would not last nearly long enough for an electron to leave the battery and return to it. In considering alternating current theory, it is obvious that an electron will seldom, if ever, have sufficient time to travel completely around the circuit, especially if the voltage alternations of the oscillator occur rather frequently. The flow of an alternating current in a wire may be pictured as follows: The current flow consists of an electron current just as in a direct current circuit, but these electrons are more or less confined to a particular portion of the wire. First, they slowly drift one way; then as the voltage reverses, they will drift the other way, but they will never get more than a short distance away from their original position. In other words, they "alternately" flow back and forth, forming an "alternating current".

Perhaps you are wondering whether or not an electric current that is continually reversing itself - never getting anywhere, so to speak - is of any use. Consider a paddle wheel in a stream of water, and to the paddle wheel are attached a number of millstones. We can grind grain between these stones if the stones are rubbing together. It does not matter whether the water flows continuously, turning the millstones in a certain direction, or whether the water flows first one way and then the other. Just as long as the millstones turn against each other, the grain will be ground and we will be doing work. In this same manner, electrons flowing through a resistor generate heat regardless of whether they flow steadily in one direction, or whether they reverse their direction periodically. If an alternating current flows through an electric light bulb, the bulb will be illuminated, and if the frequency of the alternating current is high enough, above 30 cps, the bulb will appear to be giving off a steady light. Actually, the lamp filament cools off somewhat as the alternating current goes through zero, but the eye does not detect this. Alternating current can be made to run a motor just as well as a direct current. If a condition is presented, wherein a-c cannot be used, it is a simple matter to change the a-c to d-c. An example of this is the voltage applied to the plate circuit of vacuum tubes, as mentioned previously.

Figure 6(B) is a graph of the voltage applied to the resistor in Figure 6(A) and the current which flows through this resistor. In the figure, notice that the points where the voltage passes through zero, and the points where the current passes through zero coincide, and that the voltage and current reach their maximum values at the same instant. This is true for a circuit containing resistance, but is not true if the circuit contains a coil or a condenser, or both, as we shall learn in a later assignment. When the two curves coincide as they do in Figure 6, they are said to be "in phase"; when they do not coincide, they are said to be "out of phase".

The Characteristics of Sine Waves

Suppose we plot a sine wave voltage with vertical lines at equal time intervals, as shown in Figure 7.

The time axis is marked off in degrees instead of seconds, as in Figure 4. This is possible because a cycle represents one complete succession of events, such as one turn of a wheel. In the rotation of a wheel, we could say that one complete rotation, or cycle, was 360^0, since there are 360 degrees in a circle. One half of a revolution could be represented by 180^0 rotation, one fourth of a rotation by 90^0, etc. In a like manner, the cycle of an a-c wave may be broken into degrees.

The *maximum* value of the sine wave is indicated in Figure 7. It is the greatest value to which the current or voltage rises. The notations, "I_{max}" and "E_{max}" are used to represent maximum values in radio formulas. The term *peak* value is sometimes used in place of maximum value, and means the same thing.

In Figure 7, it will be apparent that if the vertical lines are drawn long enough to intersect with the sine-wave curve, each of these lines will have a different length and each will represent the voltage at some particular instant of time. The voltage at that instant of time is known as the *instantaneous* *value of voltage*, or more commonly, the *instantaneous voltage* of the wave form. From this figure it is evident that the instantaneous voltage for a sine wave depends on the particular instant at which the voltage is measured.

Table 1 lists the instantaneous value of a sine wave, at 10° intervals, assuming that the maximum value is 1.

Table I

Degrees	Sine	Degrees	Sine	Degrees	Sine
0	0	130	.766	260	-.985
10	.174	140	.643	270	-1.
20	.34	150	.5	280	-.985
30	.5	160	.34	290	-.94
40	.643	170	.174	300	-.866
50	.766	180	.0	310	-.766
60	.866	190	-.174	320	-.643
70	.94	200	-.34	330	-.5
80	.985	210	-.5	340	-.34
90	1.0	220	-.643	350	-.174
100	.985	230	-.766	360	0
110	.94	240	-.866		
120	.866	250	-.94		

By referring to this table, we can find the value of a sine wave, at any instant, if we know the maximum value of the sine wave. For example, if the maximum value of a sine wave of a-c is 1 volt, what is the value at 30°? By looking at the table we find that it is .5 volt. If the maximum value is any value other than one, the value of the sine wave at any instant may be found by multiplying the figures in the table by the maximum value. For example, suppose we are considering a sine wave which has a maximum value of 100 volts, and we wish to know its instantaneous value at 60°. By referring to the table, we find the value of a sine wave with a maximum of 1 volt to be .866 volt at 60°. To find the instantaneous value of this 100V maximum wave at 60° we merely multiply .866 by 100 and find that the value of the 100 volt maximum wave, at 60° is 86.6 volts. Using this same principle we could find the following:

Sine wave of 100 volts max. at 30° = 50 volts

Sine wave of 100 volts max. at 20° = 34 volts

Sine wave of 100 volts max. at 180° = 0 volts

Sine wave of 100 volts max. at 270° = -100 volts

Sine wave of 200 volts max. at 190° = -34.8 volts

Sine wave of 155 volts max. at 70° = 145.7 volts

Check the instantaneous values given in the examples above, and see if you agree with each.

Another term which is sometimes used in connection with a sine wave is *average value*. The average value of a sine wave is the average height of the curve of one alternation of a sine wave. Thus, if the height of all the vertical lines of an alternation in Figure 7 were measured, and the average of them taken, this average would be found to be 0.637, or 63.7% of the maximum value. We could write this as:

$$E_{av} = 0.637\ E_{max}$$

and $I_{av} = 0.637\ I_{max}$

To apply this formula, let us use a few examples.

Example 1. What is the average value of a sine wave with a maximum value of 100 volts?

$$E_{av} = 0.637 \times E_{max}$$
$$= 0.637 \times 100$$
$$E_{av} = 63.7 \text{ volts}$$

Example 2. What is the average value of a sine wave whose maximum value is 155 volts?

$$E_{av} = 0.637 \times E_{max}$$
$$= 0.637 \times 155$$
$$E_{av} = 98.7 \text{ volts}$$

Example 3. What is the average value of a sine wave which has a maximum of 900 volts?

$$E_{av} = 0.637 \times E_{max}$$
$$= 0.637 \times 900$$
$$E_{av} = 573.3 \text{ volts}$$

By algebraic means, this formula can be rearranged as:

$$E_{max} = \frac{E_{av}}{0.637}$$

To find the maximum value, if the average value is known, this formula should be used.

Example 1. What is the maximum value of a sine wave which has an average value of 1000 volts?

$$E_{max} = \frac{E_{av}}{0.637}$$
$$= \frac{1000}{.637}$$
$$E_{max} = 1569.9 \text{ volts}$$

The fourth term which is *often* used when considering an a-c voltage or current is the *effective* value.

The term "average value" seems fairly obvious. Although there is nothing particularly difficult about the effective values, it cannot be said that they are obvious. The effective value of an alternating voltage or current (which you must remember is varying in magnitude at each instant) must be the same as a corresponding direct current value. If this were not true, then 1 volt of alternating voltage would not produce the same effect on a resistor as would 1 volt of direct voltage. Also, 1 ampere of alternating current would not produce the same heating effect in a given resistor as would 1 ampere of direct current, and you can see that this would never do.

The effective value of a sine wave of current or voltage is defined as that value which will produce the same heating effect in a resistor as will be produced by a given value of direct current or voltage. It can be shown mathematically that the effective value of a sine wave of current or voltage is the square root of the average of the instantaneous values squared. By applying this involved procedure, it can be found that the effective value of a sine wave is .707 times the maximum value.

Stated mathematically this is:

$E = 0.707\ E_{max}$ Where E is the effective voltage and

$I = 0.707\ I_{max}$ I is the effective current.

To apply these formulas let us consider a few examples.

Example 1. What is the effective value of a sine wave which has a maximum value of 200 volts?

$E = 0.707\ E_{max}$

$= 0.707 \times 200$

$E = 141.4$ volts

This means that this sine wave of a-c voltage, which reaches a maximum of 200 volts, will do the same amount of work as a d-c voltage of 141.4 volts.

Example 2. What is the effective value of a sine wave which has a maximum value of 60 amperes?

$I = 0.707 \times I_{max}$

$= 0.707 \times 60$

$I = 42.42$ amperes.

Thus we see that a sine wave of current which reaches a maximum of 60 amperes would produce as much heat in a resistor as 42.42 amperes of direct current.

Example 3. What is the effective value of a sine wave which has a maximum of 155 volts?

$E = 0.707 \times E_{max}$

$E = 0.707 \times 155$

$E = 109.6$ volts.

We could rewrite this formula as:

$$E_{max} = \frac{E}{0.707} = 1.414\ E$$

$$I_{max} = \frac{I}{0.707} = 1.414\ I$$

We would use this formula to find the maximum value of a sine wave, when the effective value is known.

Example 1. What is the maximum value of a sine wave whose effective value is 6.3 volts?

$E_{max} = 1.414 \times E$

$= 1.414 \times 6.3$

$E_{max} = 8.91$ volts.

Example 2. What is the maximum value of a sine wave which has an effective value of 20 amperes?

I_{max} = 1.414 x I

= 1.414 x 20

I_{max} = 28.28 amperes.

Example 3. What is the maximum value of a sine wave which has an effective value of 110 volts?

E_{max} = 1.414 x E

= 1.414 x 110

E_{max} = 155.5 volts.

This last example illustrates the voltage which is supplied to most homes by the electric power companies. The voltage is called 110 volts a-c. This voltage is actually a sine wave voltage with an *effective value* of 110 volts. The peak value of this voltage is 155.5 volts. All a-c voltmeters and current meters read *effective values*.

Because of the way in which they are obtained, effective values of current or voltage are frequently referred to as "root mean squared" values. This is often abbreviated "rms".

The average values of an alternating current or voltage are seldom used in ordinary radio and electronics work. *Unless the current or voltage is specifically indicated otherwise, whenever we speak of an alternating current or voltage we mean its effective value.*

Frequency and Wavelength

The wavelength of an alternating current sine wave is the actual physical length of one cycle in space. The relation between frequency and wavelength is a simple one. The wavelength is equal to the speed at which the electric waves travel divided by the frequency in cycles. This speed is equal to 186,000 miles per second or 300,000,000 meters per second (a meter is slightly longer than a yard). To get the wavelength of the wave in meters we divide 300,000,000 by the frequency or: Wavelength in meters $= \frac{300 \times 10^6}{f}$.

The customary symbol for wavelength in meters is the Greek letter lambda, written λ.

Let us take several numerical examples.

Example 1. Suppose we wish to find the wavelength of a broadcast station which operates on a carrier frequency of 1000 kc. Using the formula, we have

$$\lambda = \frac{300,000,000}{1,000,000} = \frac{300 \times 10^6}{1 \times 10^6} = \frac{300}{1} = 300 \text{ meters.}$$

This tells us that the actual length in space of this radio wave is 300 meters. This is about 985 feet.

Example 2. What is the wavelength of the radio wave from a short-wave station operating on 20 megacycles?

$$\lambda = \frac{300 \times 10^6}{20 \times 10^6} = \frac{300}{20} = 15 \text{ meters.}$$

Example 3. What is the wavelength of a television station operating on 80 m.c.?

$$\lambda = \frac{300 \times 10^6}{80 \times 10^6} = \frac{300}{80} = 3.75 \text{ meters.}$$

Some radio receiver dials are marked both in frequency and in wavelength. In some countries, (particularly in Europe), the wavelength and never the frequency of the station is shown on radio dials. Even in this country, the short waves are usually referred to by wavelength rather than by frequency, as for example the 49 meter band, the 19 meter band, etc.

A few examples will show that the lower the frequency the longer the wavelength, or to say the same thing another way, the higher the frequency the shorter the wavelength. Our 60 cycle a-c power has a wavelength of 5,000,000 meters (approximately 3,000 miles) whereas the wavelength of certain television carrier frequencies is about 1 meter.

Phase Relations of Sine Waves

Perhaps you have suspected, or have been told, that alternating currents are much more difficult to understand than are direct currents. This is not true. However, alternating currents are more complex and there are more different possibilities to consider. For these reasons, the explanations must be generalized.

One factor which makes the study of a-c more complex is the matter of phase. This has been mentioned previously, but will be discussed in more detail now. Phase is a measure of time. It shows how one sine wave is varying in respect to another sine wave of the same frequency.

When two or more sine waves, either currents or voltages, are in phase, they pass through corresponding values at the same instant. That is, they both reach their maximum positive values at the same time, they both pass through zero at the same time. they both reach their maximum negative values at the same time, and so on. Two currents that are in phase are shown in Figure 8(A). Notice that the two waves are exactly "in-step" as far as time is concerned. They are of different amplitudes, but are in phase. (Amplitude means height of the wave, or magnitude.)

When two sine waves are out of phase they do not pass through corresponding values at the same time. Figure 8(B) shows two sine waves which are 90^0 out of phase. These waves are 90^0 out of phase because they pass through corresponding values 90^0 apart on the time axis. Notice that the sine wave of current, I_1, has reached a maximum (completed $\frac{1}{4}$ of a cycle) at the time I_2 is at zero. The current I_1, is said to be *leading* I_2 by 90^0.

Figure 8(C) shows two sine wave currents which are 90^0 out of phase; but in this case, I_2 reaches its maximum 90^0 before I_1 does, so I_2 is leading I_1 by 90^0. It is just as correct to say that I_1 is *lagging* I_2 by 90^0.

In these examples we have seen the phase relationship of two sine waves of current. Figure 9 illustrates the phase relationship of two sine waves of voltage. In Figure 9(A) the two voltages are in phase, in Figure 9(B) E_1 is leading E_2 by 90^0, and in Figure 9(C) E_1 is lagging E_2 by 90^0.

In Figure 10(A) we see two sine waves 45^0 out of phase. E_1 is leading E_2 by 45^0 since E_1 is reaching its maximum 45^0 before E_2 reaches its maximum.

Figure 10(B) illustrates two sine waves which are 180^0 out of phase. These two waves go through their zero values at the same instant, but one is increasing in a positive direction while the other is increasing in a negative direction.

Figure 10(C) shows two sine waves out of phase approximately 15°. The voltage E_1 is leading E_2 by approximately 15°.

In Figure 11 we see the phase relationship of a sine wave of voltage and a sine wave of current. The voltage wave, E, leads the current wave, I, by 90° in Figure 11(A). In Figure 11(B), the current wave I leads the voltage wave E by 90°. Figure 11(C) shows the voltage wave E, leading the current I by approximately 135°.

These examples illustrate the wide variety of phase relations which will be encountered in the use of a-c in electronic circuits. You are probably wondering under what conditions these out of phase conditions occur. The answer to that question is an easy one. Any time a circuit with a-c voltage applied has either inductance (coils), or capacitance (condensers), there will be an out of phase conditions between the voltage and the current, and between the voltages at different points in the circuit.

Figure 12(A) shows an a-c generator connected to a condenser, and Figure 12(B) shows the phase relationship which results between the voltage and the current. The current is leading the voltage by 90°. The reason why this occurs will be discussed in the assignment on condensers.

Figure 13(A) shows an a-c generator connected to a coil, and the phase relationship of the voltage and current are shown in Figure 13(B). Notice that in this case, the current is lagging the voltage by 90°.

In Figure 6 we have already seen the phase relationship of the voltage and current in an a-c circuit containing resistance alone.

If an a-c circuit contains a combination of resistance and capacitance, resistance and inductance, or resistance, capacitance, and inductance, a wide variety of phase relationship may result. The amount of phase difference will be determined by the value of the individual components. This will be taken up in detail in future assignments.

The Addition of Sine Waves

In direct current circuits, we can readily find the resultant value of two voltages or currents in the same circuit since all we have to do is add their individual values. Figure 14 illustrates this. In Figure 14(A) the resultant of E_1 and E_2 is 150 volts. We find this by adding +100 and +50. In Figure 14 (B) the two voltage sources are so connected that the two emf's are opposing each other, or "bucking". To find the resultant voltage of these two in series, we add the individual values algebraically. The number, +100 added to -50 gives +50 as an answer. The resultant voltage is 50 volts as indicated in the figure.

The resultant of two or more a-c waves can be found by adding their *instantaneous values*. This is shown graphically in Figure 15 and Figure 16.

In Figure 15 we have two sine wave generators connected in series. These two generators are delivering a-c voltages which are of the same frequency, and are in phase. The maximum value of E_1 is 100 volts, and the maximum value of E_2 is 50 volts. We wish to know the resultant value of these two voltages in series. In the graph on Figure 15, we have plotted these two voltages, and the resultant of them in series. The resultant voltage is labeled $E_1 + E_2$. To obtain this curve we add the *instantaneous values* of each wave. At zero on the time axis E_1 is 0 and E_2 is 0. Adding these two we obtain 0 for $E_1 + E_2$. At 90° on the time axis, E_1 is +100 volts and E_2 is +50 volts. This gives us +150 volts for $E_1 + E_2$ at this point. At 180° both E_1 and E_2 are 0, so $E_1 + E_2$ is also zero. At 270°, E_1 is -100 volts, E_2 is -50 volts, so the resultant $E_1 + E_2$ is -150 volts. At 360° the resultant is again 0.

In Figure 16 we have two a-c generators, each delivering 100 volts maximum. The two voltages are 90° out of phase. (E_2 is leading E_1 by 90°). We wish to find the resultant of these two voltages. This is done graphically by plotting the two waves E_1 and E_2, and adding their *instantaneous values*. We find that the resultant of these two voltages is *not* 200 volts. The maximum of the resultant of these two voltages is only 141 volts. Furthermore the resultant voltage, $E_1 + E_2$, is out of phase with each of the original voltages. If Figure 16 is studied carefully, the reason the resultant voltage is not equal to the sum of E_1 and E_2 will be apparent. It is because these voltages are not acting together. In Figure 15 the two voltages were acting together, since they were in phase, but in Figure 16, the two voltages are out of phase and do not reach their maximum values at the same time. When E_2 is maximum, E_1 is at zero, and when E_1 is maximum E_2 is at zero. When E_1 is at 45° its instantaneous value is 70.7 volts, and at this same time the instantaneous value of E_2 is also 70.7 volts. This gives a resultant value of 141 volts at this time. If all other points are plotted it will be found that the sum of the two instantaneous values is never greater than 141 volts. The graph of the resultant of the two voltages shows that the resultant voltage reaches a maximum positive at 45°, a maximum negative at 225°, and goes through zero at 135° and 315°. The resultant wave is 45° out of phase with E_1 and E_2.

As an examination of Figures 15 and 16 shows, it is considerable trouble to combine alternating currents or voltages by plotting their instantaneous values, point by point, in this fashion.

These difficulties have led to the adoption of "*vectors*" for combining currents and voltages in alternating current circuits, since the use of vectors greatly simplifies the solution of many of the a-c problems encountered in radio and television work.

Vectors

Suppose that the line I_{max} in Figure 17 is revolving counterclockwise at some constant speed. This speed could be measured easily in "degrees per second" since there are 360° in a complete circle or in one revolution of the line.

As the line I_{max} revolves, let us stop it at 30° intervals (points 2, 3, 4, etc. in Figure 17) and measure its height above its starting horizontal line If this height is plotted on the vertical axis of a graph, and the horizontal axis is plotted in degrees representing the angle through which the line has turned, we would obtain the sine wave shown at the right in Figure 17.

This shows us that it is possible to develop a sine wave by a line whose length represents the magnitude of the current or voltage, and which is rotating at a rate equal to one revolution per cycle. Since it is possible to develop a sine wave, by plotting the height of the rotating line (I_{max}) above the horizontal line, it is permissible to use such a rotating line to represent a sine wave. A longer line would represent a greater current, and one which is rotating faster represents a higher frequency. In this example, I_{max} is equal to maximum value of an alternating current. Likewise we could represent a sine wave voltage by a counterclockwise rotating line having a length E_{max}.

In Figure 17 the line I_{max} has a certain definite length. It also has an arrowhead on one end of it, indicating that it has direction. We call such a quantity, one that has magnitude (length) and direction, a "vector quantity".

Using Vectors to Show Phase Relationship

The phase relationship between two sine waves of the same frequency may be indicated by vectors. Remember that a vector is a line which is rotating one revolution for each cycle. Suppose we had two sine waves and represented each by a vector. If the frequency of the two sine waves were the same, these two vectors would be rotating at the same speed. It might be compared to the spokes on a wagon wheel. As the wheel turns, each of the spokes rotate at the same rate. The angle between the two spokes remains the same. Thus, if we are comparing two sine waves of the same frequency, their phase relationship may be indicated by the angle between the two vectors. This is shown in Figure 19(B). The vector I_1 represents a sine wave current, and the vector I_2 represents another sine wave current of the same frequency. The two currents are 45° out of phase. They are both rotating at a rate of one revolution per cycle and thus the two vectors rotate "in step" just as the spokes of a wheel. The 45° angle will be maintained between these two vectors (spokes).

Remember these things concerning vectors. 1. A vector may be used to represent a sine wave of voltage or current. 2. A vector is considered to be rotating one revolution per cycle, in a counter-clockwise direction. 3. The length of a vector represents the amplitude of the voltage or current. 4. A vector has direction as indicated by the arrow. 5. Phase relationships between two or more sine waves can be indicated by the angle between the vectors used to represent these waves.

The Addition of Vector Quantities

We represent alternating sine wave currents or voltages by vectors since it is much simpler to add together two vectors which represent the two currents or voltages, than it is to add the two sine waves, point by point. Because of this, the solution of most alternating current problems involves vector addition, so let us see how this is done.

An ordinary unit, such as an ohm, expresses only a quantity, and so we can add ohms directly. A vector, however, has both magnitude and direction, so they must be added in such a manner that these two things (magnitude and direction) are considered.

In Figure 18(A) we have shown a small portion of a radio circuit. We have a junction where two alternating currents combine and flow in one common wire. The amount of current in two of the wires is known. The phase angle between the two currents is also known. The current in the common wire is to be determined.

If practical, you would merely insert an ammeter in the common wire to measure the combined current I_t. In studying a circuit diagram, or in a good many actual circuits, it will not be possible to insert an ammeter in the common wire to measure I_t, the sum of I_1 and I_2.

The known currents I_1 and I_2 are each 3 amperes and I_2 is known to be leading I_1 by 45 degrees. The two currents are said to be 45 degrees out of phase. We can plot the waveforms of I_1 and I_2 on the same axis and add their instantaneous values to obtain the waveform of I_t. See Figure 18(B) Notice that we are careful to plot the waveforms of I_1 and I_2, 45 degrees out of phase. The waveform of I_t has a maximum value of approximately 5.5 amps. The waveform of I_t lags I_2

by 22.5 degrees and leads I_1 by 22.5 degrees. The only fault we can find in this solution is that it takes a lot of time and careful work.

In Figure 18(C) we have added I_1 and I_2 and determined I_t by means of vectors. You can see at a glance that the vector solution doesn't involve much work. The vector solution gives us the same answer as the more tedious addition of waveforms.

It does not take a mathematician to set up and add I_1 and I_2 using vectors. Choose a convenient scale, say 1/4 inch equals 1 ampere. The lengths of the arrows indicate the amounts of each current in amperes. The vectors representing I_1 and I_2 should each be 3/4 inches long since I_1 and I_2 are each 3 amperes.

First draw a line 3/4 inches long as shown in Figure 19(A). Label this vector I_1. The vector representing I_2 will also be 3/4 inches long. I_2 is known to be leading I_1 by 45 degrees. We will have to have a 45 degree angle between the vectors representing I_2 and I_1. To indicate that one sine wave is leading another, the leading vector is drawn on the counterclockwise side of the other vector. In Figure 19(B) we see the vector I_2 drawn on the counterclockwise side of I_1 and the angle between the two lines is 45^0. Now we have drawn the vectors representing the two sine waves. The length of each vector indicates the amplitude of each sine wave, and the angle between them (45^0) indicates the phase relationship between them. As mentioned previously, each of these vectors is rotating, but since their speed of rotation is equal, they will maintain the 45^0 angle between them. For all practical purposes, we could "stop" the rotating vectors in some convenient position and analize them.

There are several ways of adding vectors, but the most simple method is shown in Figure 19(C). To find the resultant (the sum of the two) of I_1, and I_2, we "complete the parallelogram". To do this, from the tip of the arrow I_2, we draw a line which is parallel with I_1. This is the dotted line (a) in Figure 19(C). Then from the tip of I_1 draw a line which is parallel with I_2. The sum of the two or the resultant, then, is represented by the line drawn from the "tail" of I_1 and I_2, to the point where these two dotted lines cross. This is the solid line I_t in Figure 19(C). The angle that this line has in respect to the two other vectors indicates the phase angle, and the length of the line represents the magnitude of the voltage. If we were to measure the angle of I_t, in respect to I_1 and I_2, with a protractor, (a device for measuring angles), we would find that I_t leads I_1 by 22.5^0 and that it lags I_2 by 22.5^0. Its length is 1 3/8 inches. Since we have used 1/4 inch to represent one ampere, the 1 3/8 inch long resultant would indicate 5.5 amps. This is the same information as obtained in Figure 18(B), but is found much more simply by using vectors.

To further illustrate the use of vectors, let us consider Figure 20. In this figure we have two oscillators (a-c generators) connected in series across a resistor. One oscillator is putting out 2 volts. We call this voltage E_1. The second oscillator is putting out 1 volt. We call this voltage E_2. The second oscillator voltage E_2, is lagging E_1 by 60 degrees. How much voltage do we have across the resistor? We could plot the wave forms of the two voltages and add the instantaneous values as shown in Figure 20(B). The easy method will involve just a few strokes of a pencil for rapid vector addition. This is shown in Figure 20(C). Draw the first oscillator voltage to a convenient scale representing 2 volts. [E_1 of Figure 20(C)]. Draw the second oscillator voltage vector half as long (1 volt) and of such direction that it indicates a lag of 60 degrees. [E_2 of Figure 20(C)]. Add the two vectors by the method shown in Figure 19(C), and the combined voltage across the resistor E_t can be quickly scaled and found to be approximately 2.65 volts. A protractor will show that E_t "lags" E_1 by about 19 degrees and "leads" E_2 by about 41 degrees.

Figure 21(A) shows the vectors for the wave forms shown in Figure 16. Study this vector diagram and see if it doesn't convey the same information as the wave shapes shown in Figure 16(B).

Figure 21(B) shows the vectors for the voltages shown in Figure 15. Notice that since the two voltages are in phase, they are laid out on the same line, "tail to head". The resultant voltage is equal to the total length of the line, or 150 volts in this case.

Figure 21(C) shows a vector representation of the voltage and current associated with a condenser. Compare this with the wave forms shown in Figure 12.

Figure 21(D) shows a vector diagram of the voltage and current of a coil. Compare this with Figure 13(B).

These examples will serve to introduce the subject of vectors. Other applications of vectors will be made from time to time in the training program. We shall make use of this simple way of representing sine waves in the explanation of a great deal of a-c circuits.

A-C Waves, Other than Sine Waves

A-C voltages and currents which have sine-wave shapes are encountered to *a great extent* in electronic and television circuits, but there are some cases where a-c voltages and currents will be found which have wave shapes differing from sine waves. In Figure 3 we have seen one of these wave shapes, that of a square wave. Figure 22 shows another wave shape that is sometimes encountered in radio equipment, especially certain types of test equipment, and is frequently encountered in television equipment. This wave is an a-c wave, since it is periodically changing in magnitude and direction. This wave shape is called a saw-tooth wave due to its resemblance to a tooth on a saw. Another wave shape which differs from a sine wave is the audio signal which we have mentioned previously. The wave shape of a typical audio signal is shown in Figure 23. Before discussing this wave shape let us review briefly how this signal is developed.

Any vibrating body will set up sound waves in the air. For example, when a key is struck on a piano, the hammer strikes the string, setting it into a state of vibration. The vibrating string sets up sound waves in the air, by causing regions of higher than normal, and lower than normal air pressure to travel away from the string. When these sound waves strike the diaphragm of a microphone, they cause the diaphragm to vibrate. The microphone then changes these vibrations into audio signals, which are sound waves in an electrical form.

You may have wondered why different musical instruments have a different sound when playing the same note. For example, if middle C is played on a piano, and on a horn, it does not sound the same. Actually, both of these notes are of the same frequency, (the number of times per second that the vibrations are occuring), but the difference in sound is due to the difference in wave shape. As the sound waves strike the diaphragm of a microphone, the vibration of the diaphragm is directly "in step" with the sound wave. It produces audio signals which correspond to the sound waves, not only in frequency, but also in amplitude. The amplitude of the audio signal will vary in step with any irregularities in the sound waves. In this way, audio signals are not pure sine waves, but are closer to the wave form shown in Figure 23. The wave shape of an audio signal produced by the sound waves from a vibrating string may be closer to a pure sine wave than that in Figure 23, but the audio signal produced by a human voice is much more irregular than the wave shape shown in Figure 23. The characteristic sounds of different instruments and voices is due to the wave shape of the sound waves produced. As was pointed out previously, the frequency of audio signals range from 20 cycles to approximately 20,000 cycles.

Harmonics

Harmonic is the term which is used to define some multiple of a fundamental frequency. For example, the second harmonic of a 60 cycle signal is 120 cycles, the third harmonic is 180 cycles, the fourth harmonic is 240 cycles, etc.

Figure 24 shows a fundamental and its third harmonic plotted on the same graph.

This assignment has presented a large amount of information about alternating current and voltages. To summarize, let us put some of this in the form of definitions.

Definitions

Pulsating d-c - A current which is always in one direction, but which is varying in amplitude.

Alternating Current or Voltage - A current or voltage that periodically changes in magnitude and direction.

Cycle - One complete succession of events. Applied to a sine wave; from zero to a maximum, back to zero, to a maximum of opposite polarity and back to zero again. It is equal to 360 electrical degrees.

Frequency - Number of cycles per second.

Power Frequencies or Commercial Frequencies - The frequencies of the a-c power delivered to homes. In most localities the a-c frequency is 60 cycles per second. In some cases 25 cycles and 50 cycles are used.

Audio Frequencies - The frequencies which are in the range of the human ear-approximately 20 - 20,000 cycles.

Radio-Frequencies - Frequencies higher than 20,000 cycles.

Period - Length of time required for one cycle.

Instantaneous Value - The value of voltage or current for any given instant.

Peak Value of a Sine Wave - The maximum value of voltage or current during one cycle. It is equal to 1.414 times the effective value.

Effective or RMS Value of a Sine Wave - That value of the sine wave which will produce the same heating effect as the same amount of d-c voltage or current. Numerically it equals .707 times the maximum value of the sine wave. This is the value which is read by a-c meters.

Average Value of a Sine Wave - The average of all the instantaneous values for one alternation. It is equal to .637 times the peak value.

Harmonics - Multiples of a fundamental frequency.

Phase Relationship - A measure of the time difference in degrees of two sine waves of the same frequency, in reaching corresponding points on the same time axis.

Vectors - Rotating lines which may be used to represent sine waves. The length of each vector is determined by the magnitude of the sine wave, and the angle between vectors is determined by the amount of phase difference.

Wave Shape - Sine waves are the one most commonly encountered. Others which may be found in radio circuits are square waves, saw-tooth waves, and audio signals which are irregular in shape.

In future assignments, we shall apply our knowledge of a-c to the subject of coils and condensers, and find out how each of these circuit components react to alternating currents and voltages. We will then be in a position to study one of the most fascinating subjects in radio - the action of coils and condensers in combination.

Test Questions

Be sure to number your Answer Sheet Assignment 13.
Place your Name and Associate Number on *every* Answer Sheet.
Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. What is a direct current which is changing in magnitude, called? pulsating

2. What is the frequency of the a-c voltage supplied to most homes in the United States? cycles

3. Does an a-c meter read; peak, effective, or average values of a-c?

4. If the peak value of an a-c voltage is 300 volts, what is the effective value? 212.1

5. An a-c voltage has a frequency of 10,000 cycles per second. Is this called an Audio Frequency or a Radio Frequency?

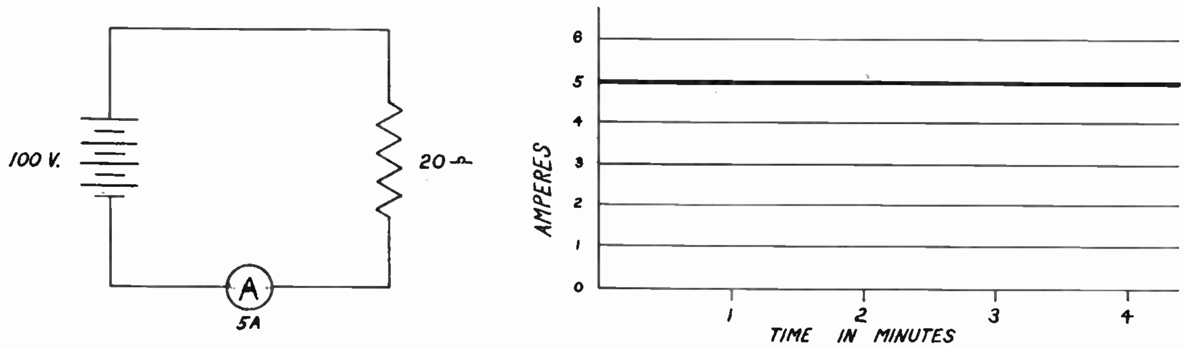
6. What is the frequency of the third harmonic of a 100 cycle a-c voltage?

7. Draw the vectors for the following:
   Two a-c voltages, each of 100 volts maximum, and 90° out of phase.

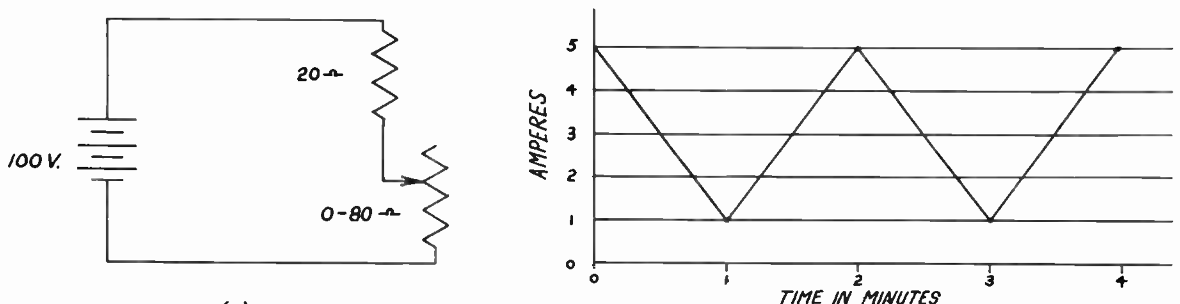
8. Use the values given in Table I on page 8 and draw a sine wave.

9. Which can be changed from a low value to a high value easier, a-c or d-c?

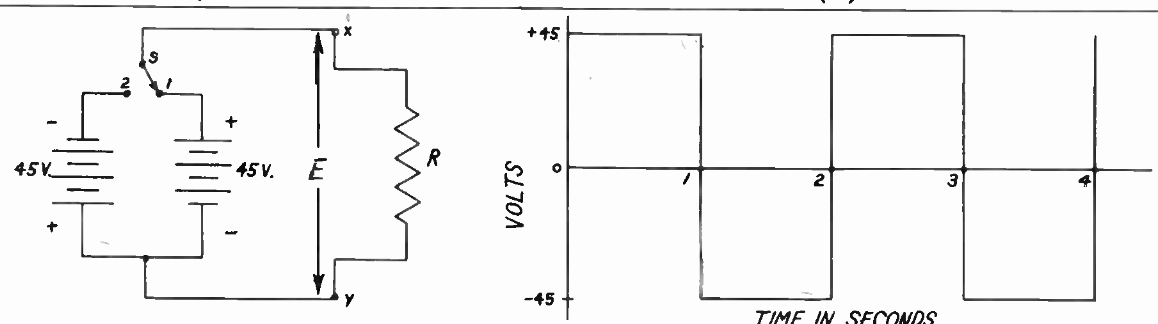
10. The effective value of voltage delivered to most homes is 110 volts. What is the peak value of this voltage? 155.5



(A) FIGURE 1 (B)



(A) FIGURE 2 (B)



(A) FIGURE 3 (B)

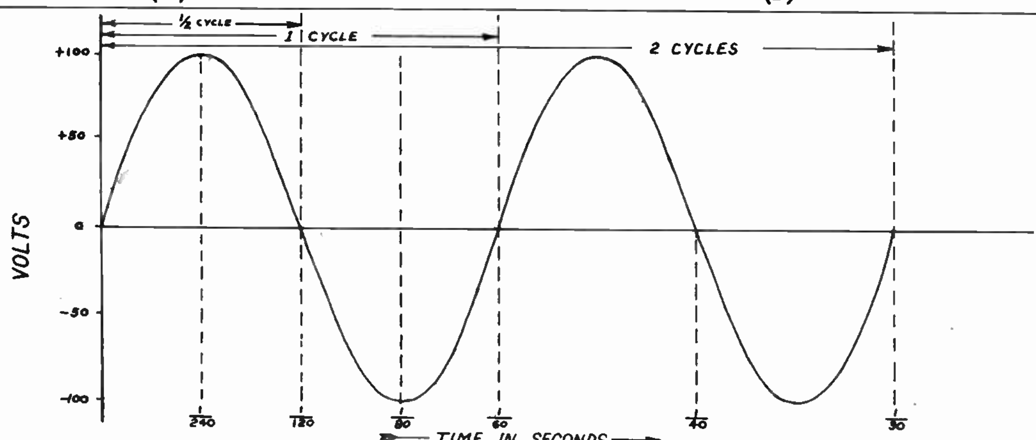


FIGURE 4

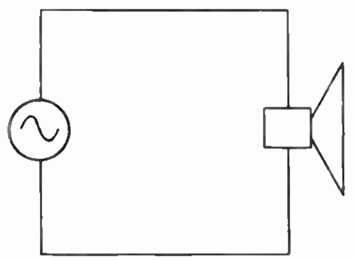


FIGURE 5

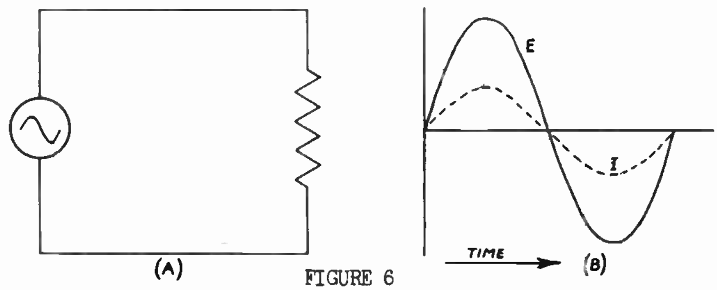


FIGURE 6

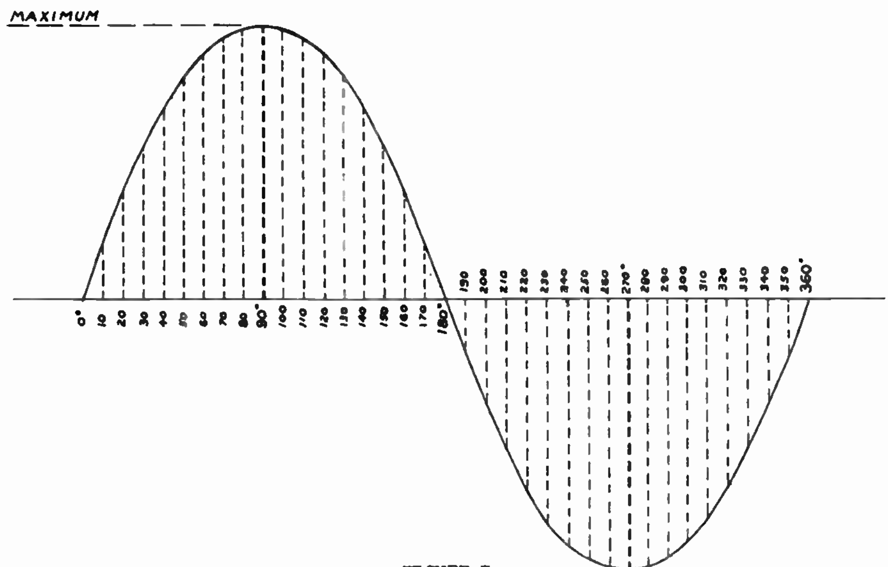


FIGURE 7

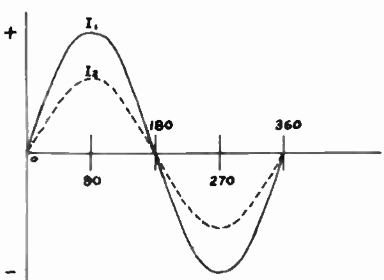


FIGURE 8-A

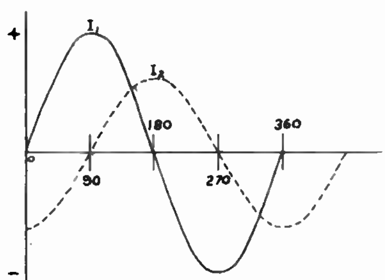


FIGURE 8-B

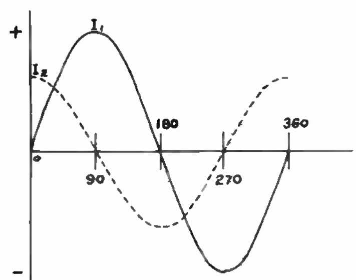


FIGURE 8-C

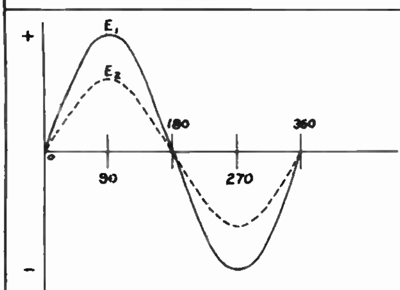


FIGURE 9-A

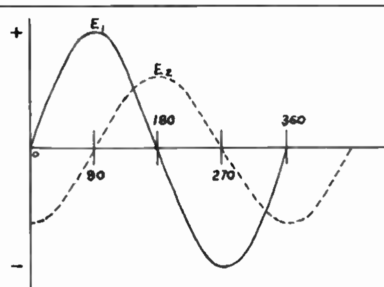


FIGURE 9-B

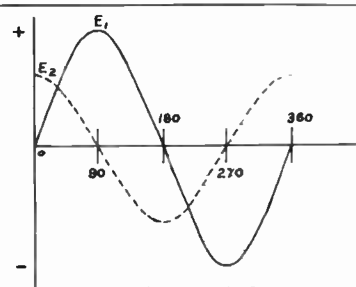


FIGURE 9-C

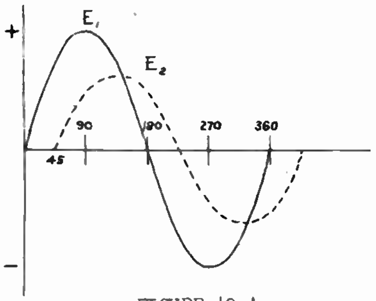


FIGURE 10-A

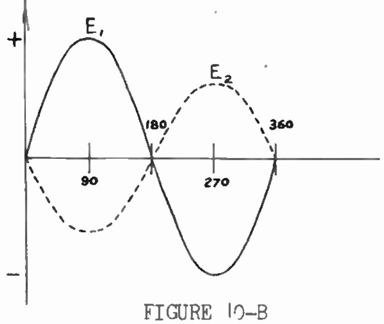


FIGURE 10-B

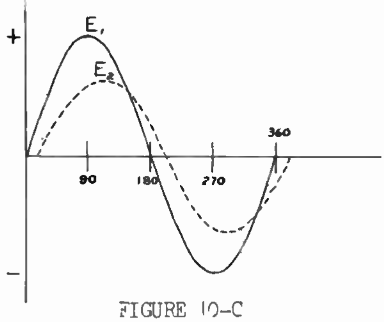


FIGURE 10-C

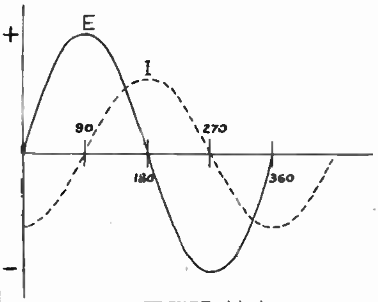


FIGURE 11-A

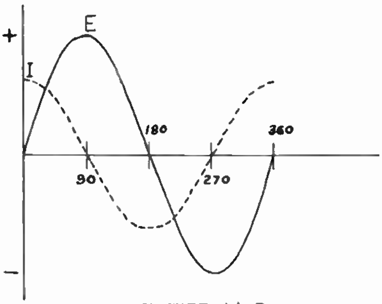


FIGURE 11-B

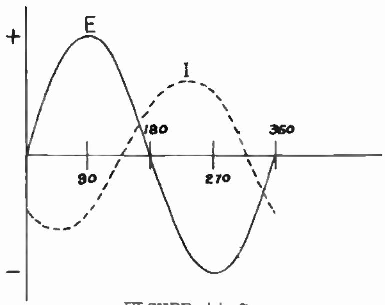


FIGURE 11-C

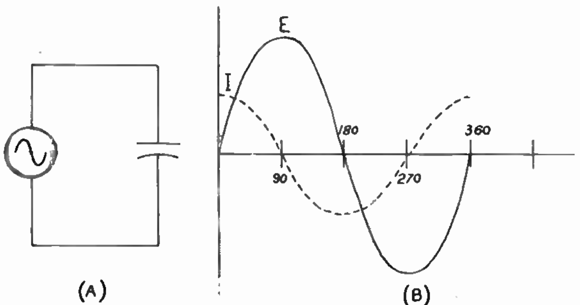


FIGURE 12

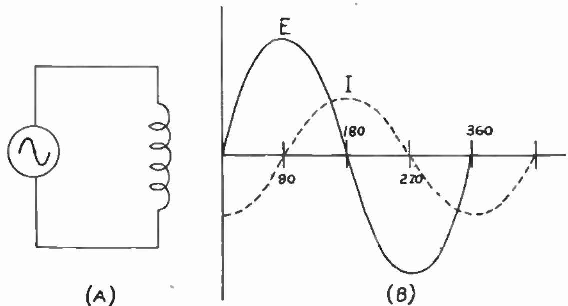


FIGURE 13

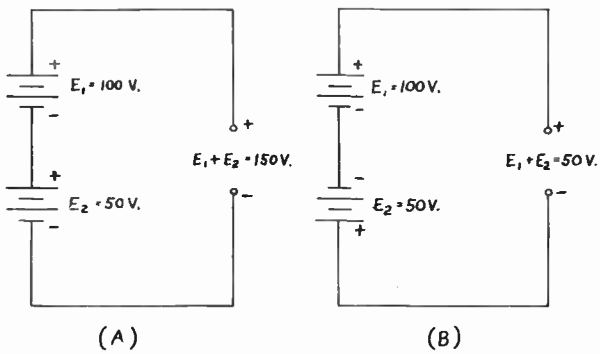


FIGURE 14

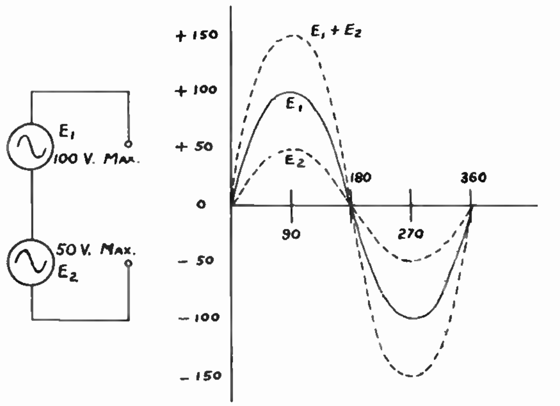


FIGURE 15

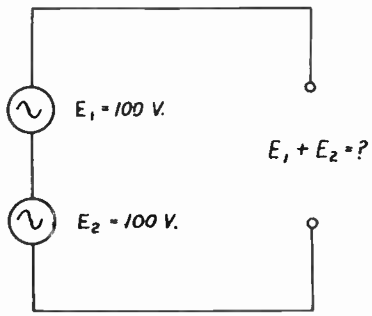


FIGURE 16-A

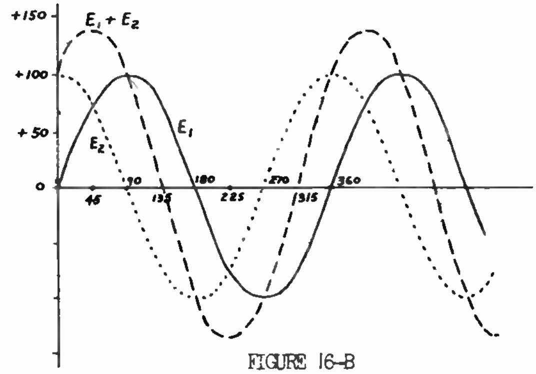


FIGURE 16-B

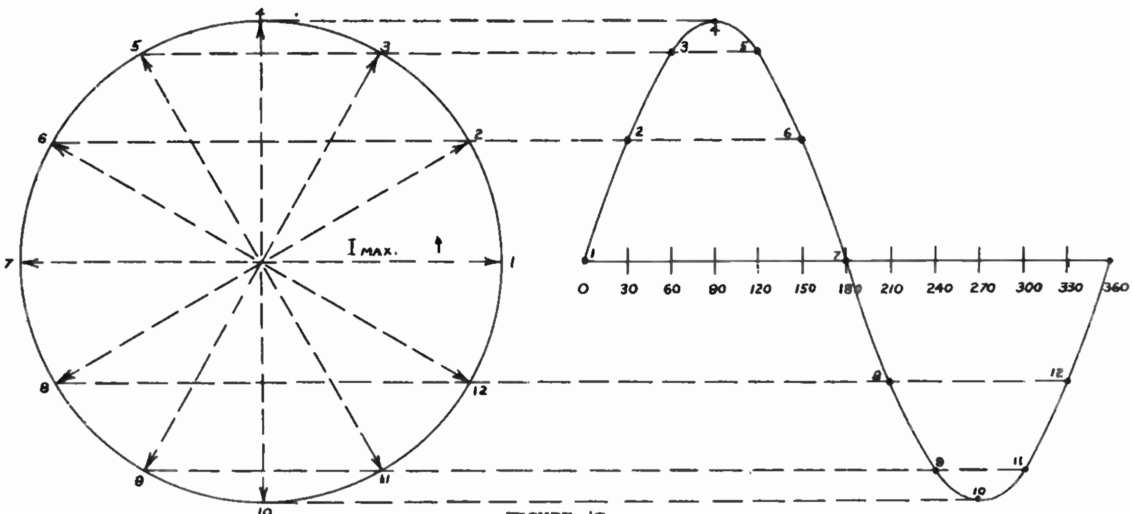


FIGURE 17

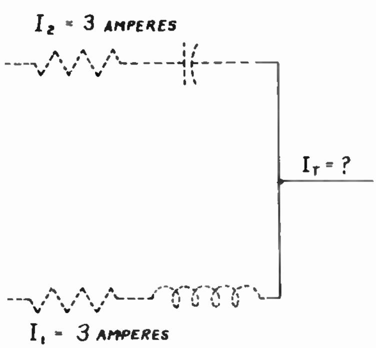


FIGURE 18-A

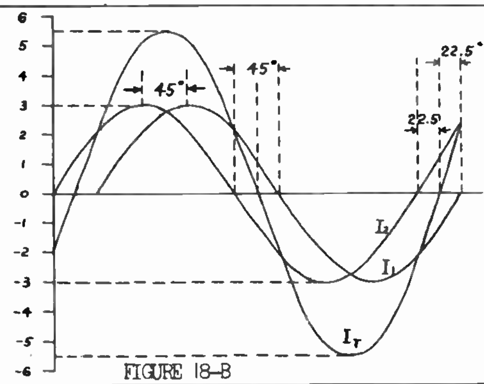


FIGURE 18-B

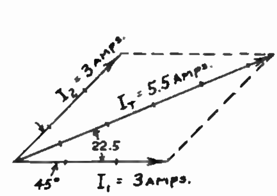


FIGURE 18-C

FIGURE 19-A

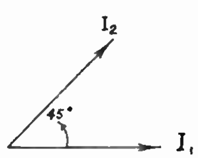


FIGURE 19-B

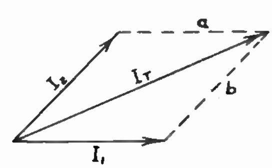


FIGURE 19-C

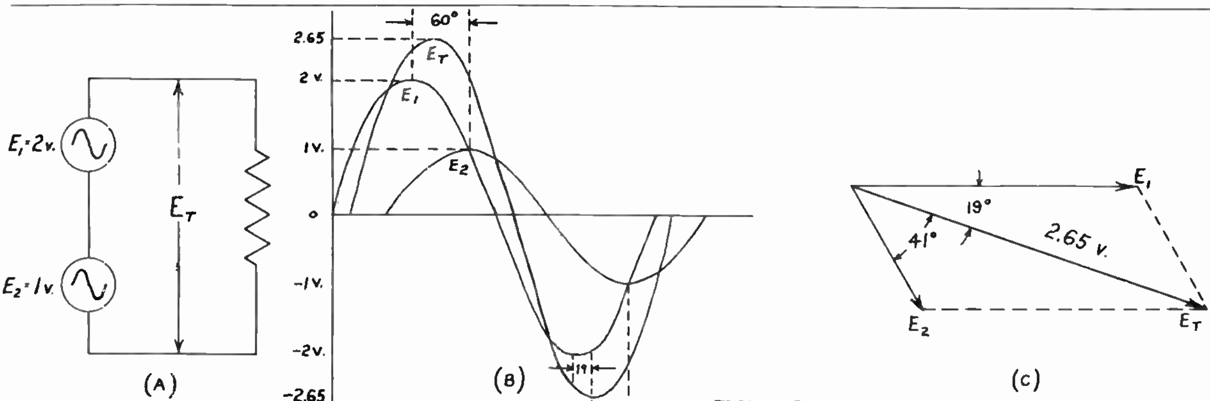


FIGURE 20

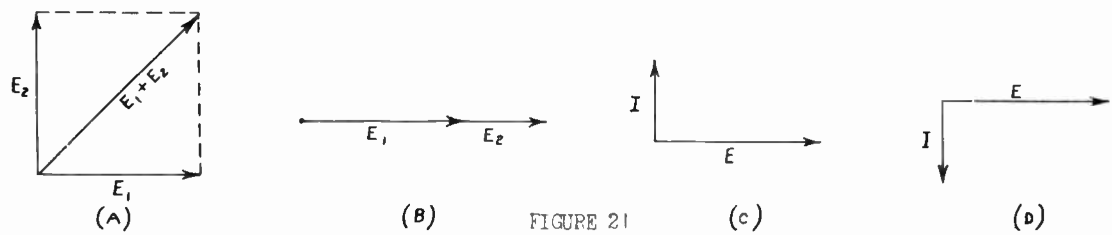


FIGURE 21

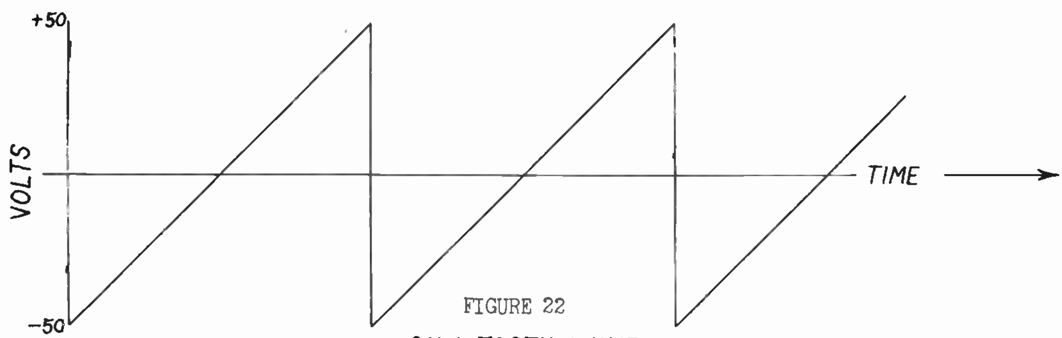


FIGURE 22

SAW TOOTH WAVE

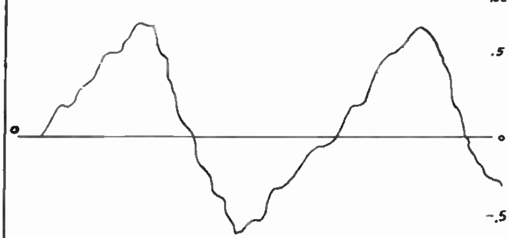


FIGURE 23

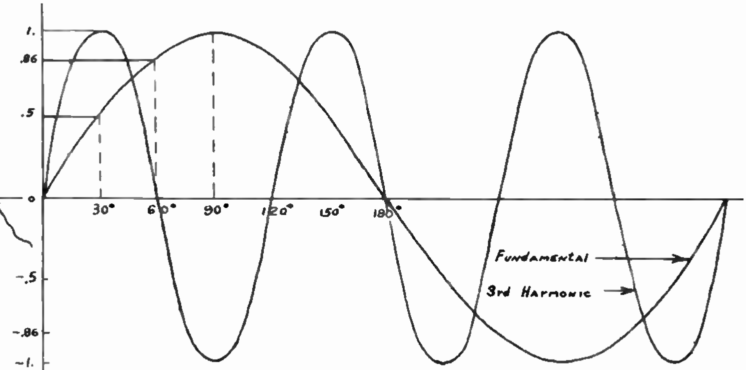


FIGURE 24

Electronics

Radio

Television

Radar

UNITED ELECTRONICS LABORATORIES

LOUISVILLE KENTUCKY

RADAR PRINCIPLES **ASSIGNMENT 13B**

A C K N O W L E D G E M E N T

United Electronics Laboratories gratefully acknowledge the aid and assistance of the Sperry Gyroscope Company in the preparation of this material.

ASSIGNMENT 13B

RADAR PRINCIPLES

The present international situation is such that it is thought necessary to provide the Associate with information which will be valuable in defense industries and in the Armed Forces. In regard to this matter it should be mentioned that there are many civilian positions available in connection with the Armed Forces. Civilians are used very widely in the maintenance and repair of electronic equipment of the Armed Forces as well as in the design and manufacture of this equipment. For this reason special assignments will be included in the training program at appropriate points dealing with the subject of radar. This is the first of these special assignments dealing with this subject.

Introduction and History of Radar

The best definition of radar is obtained by analyzing the actual meaning of this term. The word Radar is an abbreviation of the following: Radio Detection and Ranging. The term radar is, then, an abbreviation of the longer phrase, radio detection and ranging, which indicates the actual purpose of radar equipment. In military usage the term range means a measure of distance between some object such as a gun, or a radar set in this case, and some objective. Thus radar is used to detect the presence of objects and to determine the distance of the object from the radar set. Not only does radar indicate the distance to an object but it also indicates the direction of that object.

To acheive the desired results, radar sets employ radio waves. Consequently, the history of radar dates back to the beginning of radio experiments. Thus Heinrich Hertz's crude radio experiments in the year 1888 and Marconi's experiments which followed in the year 1896 actually laid the cornerstone for the complex radar installations of today.

The major developments in radar equipment occurred during the years between 1935 and 1945—that is, prior to and during World War II. However, radar was not entirely unknown before that time as Marconi predicted it in the year 1922.

It is interesting to note that nature has been employing a principle quite similar to radar probably since the beginning of time. One thing which mystified biologists for many years was the fact that bats are able to fly in absolute darkness, for example, in a cave far below ground, and still they do not strike the walls or other objects. However, since the darkness is absolute, it is not possible for them to "see" the objects. Thus it remained a mystery for many years just how the bats "achieved the impossible". It has been found that the system employed by these animals to achieve the impossible is quite similar to radar.

The bats produce very high pitched sounds, so high pitched in fact that they are not audible to the human ear. These high pitched sounds are reflected from the walls of the caves or other objects and returned to the bat. When these returned "echos" are received by its sensitive ears the bat is able to determine the position of the object producing the echo and make the necessary corrections in the line of flight to prevent collision. This is illustrated in Figure 1.

Before considering the subject of radar in more detail let us consider a little further "nature's radar system" as employed by the bat. Notice that in the first place the bat must produce or radiate, some sort of sound or signal which can be heard by its ears. As this signal travels away from the bat it strikes the walls of the cave and other obstacles nearby. Part of the energy striking the walls of the cave or other objects, is reflected back toward the bat, forming an echo. Thus the second requirement in the natural radar system is the reflection of the energy. The energy which is reflected to the bat must be picked up, or "received", by the bat's ears. This illustrates the third requirement of the radar system; namely a receiver. However, this entire process would be useless if the bat did not possess some means of interpreting the echo and indicating the direction and position of the object causing the echo. This, in the case of the bat, is accomplished through its brain or instinct. We might for simplicity, call this portion of the natural radar system an indicating device. To summarize this action it can be stated that the fundamental requirements of the natural radar system are: (1) a means of generating and radiating a signal, (2) an echo from the object to be detected, (3) a means of receiving this signal and (4) a means of interpreting the signal and indicating the position and distance of the object.

As we shall soon see, the same fundamental components are required in a radar system. It should be emphasized that there is one fundamental difference between the radar system of the bat and the radar system which is used to practical advantage in military and civilian applications. This is the fact that the signal radiated in radar systems is a radio frequency wave, whereas, the bat employs high frequency sound waves.

Radar Applications

The first radar systems were designed for use in detecting the presence of aircraft while they were still at a sufficiently great distance so they could be intercepted by fighter aircraft. This is still one of the major applications of radar. However, other types of radar systems have been developed for use in many other situations. For example, modern radar equipment is available for locating exactly the position of an aircraft, which is nearby, so that this information can be used in directing anti-aircraft fire. This equipment has been developed to the point where the radar device actually controls the position of the anti-aircraft guns thereby greatly increasing their accuracy. These applications of radar are normally referred to as ground radar, since the equipment is located on the ground.

Another important application of radar is airborne radar. There are a number of different types of radar equipment which are airborne. One type, which is used primarily by fighter planes, enables the pilot to "see" an enemy aircraft at night and thereby enable interception. Another type of radar which is used largely by bombers, enables the crew to "see" the terrain over which the plane is flying at night or in the case of heavy fog or bad weather conditions. This is particularly important in locating a target for high level pin-point bombing.

A third application of radar to aircraft is the radar altimeter. This device is far more accurate than the customary altimeter and is very important in connection with bombing missions as the exact altitude is an important factor in determining the proper time to release the bombs.

Another radar application which is used in conjunction with aircraft is the radar landing system. Strictly speaking, this is a ground radar application since the equipment is located on the ground. During World War II, when targets in Germany were being bombed by aircraft stationed in England, the facts indicated that the number of planes lost during landing operations were nearly as great as those lost by enemy action over the target. Thus it was obvious that a landing method must be devised for use in case of bad weather conditions. Special radar equipment was designed for this purpose which enables an operator on the ground to determine very accurately the position of a plane approaching an airport. Directions can be given to the pilot by radio telling him the necessary corrections to make in his glide path and direction of flight so that he is able to make a perfect landing. This equipment has also been adapted for use in commercial airlines and is called Ground Controlled Approach (GCA).

Radar is also used widely on naval vessels. This equipment is quite similar to ground radar except it is, of course, adapted for use at sea. The equipment used includes radar units for detecting and indicating the range of other surface vessels, or long range detection of aircraft, for position indication of close-flying aircraft and for anti-aircraft gun direction. Another marine application of radar is in navigation, particularly in the case of bad weather or darkness when a ship is close to shore. When a ship is approaching port etc., radar may be used to determine the distance to the shoreline, bouys, other ships, etc., to assist in the navigation of the vessel.

While the foregoing does not constitute a complete list of the uses of radar it does outline its major uses. It should be very evident to the Associate that the types of radar equipment used to perform the various types of operations differ rather widely. For this reason the detailed study of particular units is impossible in the training program. However, since all radar equipment operates on similar principles, the basic radar circuits and principles which will be included in the training program should enable the Associate to intelligently analyze any radar equipment with which he may have association in the future.

A Fundamental Radar System

Figure 2 illustrates the fundamentals of a radar system. A radar transmitter generates very short radio waves which are radiated by the radar antenna. The transmitter is turned on and off automatically in such a manner that the radio waves transmitted are in the form of pulses, somewhat similar to a sucession of dots being sent by code (radio telegraph) station, except the radar pulses occur for shorter intervals of time. As the radio waves travel through space they will strike objects which reflect a portion of the radio wave back toward the radar antenna. A receiver is connected to the antenna in such a manner that the reflected waves are picked up and amplified and are then passed on to the visual indicator. The indicator consists of electronic circuits and a cathode-ray tube similar to those used in television receivers. The effect of the returning pulse is to produce an indication on the indicator which can in turn be used to determine the distance from the radar set to the object which caused the reflected radio wave to occur. In addition directional antennas are employed with radar equipment so that the radio waves which are transmitted are sent out in a narrow beam somewhat similar to the beam from a flashlight. Thus the reflection occurs from a particular object only when the antenna is aimed at that object and the direction the antenna is pointing may be used to indicate the direction of the object. Thus an object can be detected and its range and direction can be determined by radar.

The fact that radar employs a radio wave instead of other means of indicating the presence of objects, enables it to offer a decided advantage over other detection methods. For example the presence of approaching planes can be detected by constantly searching the sky with a pair of powerful binoculars. However, the range of detection in this case is very limited and in case of fog or other adverse weather conditions this method of detection is almost useless. Another method of detection, which was employed previous to radar, was a sensitive listening device, which could be used to detect the sound of the motors of the approaching plane. This method too, is very limited in range and is very inaccurate. The radio waves used by a radar system are, however, unaffected by fog or other similar weather conditions and the useful range of the instrument can be extended in excess of one hundred miles. Also, radar can be used to detect objects which are dark and silent and therefore could not be seen nor heard. An aircraft flying at a very high altitude can determine the location of a target area even though that target area is blanked out and silent. This importance is so obvious that no additional discussion is required.

Almost any object can be detected by means of radar since practically all materials reflect the short radio waves used by radar. For example ships, aircraft, land, water, trees, buildings, birds, etc., will cause radar reflections to occur. It should be emphasized however that different objects reflect the radar waves to a different degree, thereby enabling detection to occur. It was mentioned that a radar wave is reflected from water and also that it was reflected from a ship; consequently, it might appear that a ship in the water could not be detected. This, however, is not the case since the metal of a ship reflects the radar waves and returns them to the radar antenna to a greater degree than does the water. Thus the presence of the ship will be indicated by the fact that its reflection is greater than the reflection of the water.

To state this in a general manner it can be said that the radar reflection which occurs is dependent upon the material of the object which is being struck by the radar beam and upon the size and shape of that object. Metal is one of the best reflectors; consequently, metal ships, airplanes, etc., produce better reflected waves than do wooden ships or plywood aircraft.

The fact, that a large object causes a greater echo to occur than a small object, should be readily understood. Thus a radar set is capable of detecting the presence of a large object at a greater distance than it can detect a smaller object. In this respect the radar antenna compares with the eye since a large object can be seen at a greater distance than the small object.

As mentioned in Assignment No. 1 radio waves travel at the speed of light which is approximately 186,000 miles per second. Not only do radio waves travel with the speed of light but, their reflection characteristics are in many respects, similar to the reflection characteristics of light. This effect is illustrated in Figures 3 and 4. Everyone is, of course, familiar with the effect produced when a beam of light shines upon a sheet of smooth metal. As illustrated in Figure 3(A), if the metal has a flat smooth surface, the light rays are reflected. In a similar manner radio waves are reflected from the sheet of metal as shown in Figure 3(B). The amount of light reflected toward the source from the sheet of metal is determined by the position of the sheet of metal. This condition can be seen by comparing the illustrations in Figures 3(A) and 4(A). When the position of the sheet of metal is such that the surface is turned toward the source of the light, a strong reflection is returned toward the source as illustrated in Figure 4(A). Similarly the reflected radar waves returned to the source is far greater when the surface of the sheet of metal is turned toward the radar antenna as illustrated in Figure 4(B).

In most instances an object which is to be detected by radar does not consist of a single flat surface (for example, the sheet of metal in Figures 3 or 4), but has instead an irregular shape. However, for most any position of an irregular surface there will be some portions of the surface which are turned directly toward the source. This is illustrated in Figure 5. It will be noted that the waves reflected toward the source from the irregular surface, shown in Figure 5, are less than those returned from the flat surface, as shown in Figure 4, because a great deal of the energy is reflected in other directions. However, it should be obvious that a portion of the energy is reflected back toward the source. This effect can be summarized by stating that although reflection occurs from the irregular surface, only those portions of the surface which are facing the source produce reflections which are returned to the source. In other words, only the portions of the surface of an object which are at right angles to the line of approach of the waves produce reflections which are returned to the source. However, any object to be detected by a radar set has portions of its surface at right angles to the radar set and will thereby produce reflections which return to the radar set. Figures 6 and 7 illustrate the manner in which this effect enables a radar set to distinguish between objects. Notice for example in Figure 6 that some of the metal surfaces of the ship face directly toward the radar set and thereby produce strong reflections in the direction of the radar set. It can be seen moreover that the radio waves strike the surface of the water at a glancing angle and the major portion of the reflected waves from the surface of the water go off at various angles and do not return to the radar set. Since the surface of the water is not entirely smooth, a small amount of reflection toward the radar set will occur, but, because this reflection is very small in comparison to the reflections from the ship, the ship is easily identified.

Figure 7 illustrates the similar effect produced when the radar set is carried by a plane. The glancing angle at which the waves strike the flat surface of the earth or the water cause reflections, very few of which return to the radar set, but a strong echo is returned to the radar set from the surfaces of the buildings in the city. It can be seen also that the reflections returned to the radar set from the hillside are greater than those from the flat countryside.

The maximum range at which an object can be detected by radar depends upon two factors; the amount of reflected signal obtained from that object, and the sensitivity of the radar receiver. As long as the reflected energy is sufficiently great to produce the required indication on the indicator screen, the object can be detected. There are, however, a number of factors which determines the amount of reflection obtained from an object. Foremost among these are: (1) the size, shape and composition of the object, (2) the power of the signal radiated from the radar transmitter, (3) the distance of the object from the radar transmitter, (4) the width of the radar beam and (5) the terrain.

Let us now consider how these various factors effect the amount of radar signal which is reflected from an object.

The manner in which the size, shape and composition of an object affects the reflected wave was dealt with previously and needs no further explanation. The manner in which the power radiated from the radar transmitter affects the reflected signal should also be rather obvious. Compare this effect with a searchlight. If it is desired to see an object at a relatively great distance a powerful searchlight must be used. Similarly the greater the power transmitted from the radar antenna the greater will be the distance at which a particular object can be detected. In connection with this point it should be emphasized that all the power radiated by the transmitter does not strike an object. In fact only a very small portion of the power radiated ever strikes the object. This condition arises because the beam from the radar antenna is a divergent beam. In other words this beam becomes gradually wider as the distance from the antenna increases. Thus the strength of the signal striking a given object is much less than the transmitted power.

The diverging or "fanning" of the radar beam also accounts for the fact that the amount of reflection received from an object is dependent upon the distance of the object from the antenna. This effect can be compared to the effect produced by a flashlight with a divergent beam as illustrated in Figure 8(A). Practical experience will tell the Associate that the object held at position No. 1 in Figure 8(A) will be illuminated to a greater degree than it would if held at position No. 2 in the beam of the flashlight. (When reading this assignment material, if at night, you move relatively close to the light because the illumination is greater there. The farther you move away from the light the lesser is the illumination on the page.) Figure 8(B) illustrates the similar effect which occurs in a radar system. If the object, as represented by the plane in Figure 8(B) is at position No. 1 which is close to the radar antenna, the radio energy which strikes the plane will be strong, consequently the reflected signal will be strong. If the plane is in the position illustrated as No. 2 on Figure 8(B) the radio energy striking the plane is less and the reflected signal is reduced a proportional amount.

The fact that the width of the radar beam affects the amount of radio signal reflected from an object at a given distance is illustrated in Figure 9. Once again comparison is made to a similar situation with a flashlight. It was pointed out previously that the energy transmitted from the radar antenna is in the form of a beam. In different types of radar installations which are serving different purposes the width of the beam varies. If one of the prime objectives is to detect objects at a great distance a narrow beam will be employed. To understand why this is true, examine Figure 9 carefully. Notice in Figures 9(A) and (B) the same flashlight is used. However, in Figure 9(A), the lens is so adjusted that a wide-angle beam is produced and the object is only dimly illuminated. Contrast this with the condition shown in Figure 9(B) where the lens is adjusted to produce a narrow beam. Note particularly that in each case the actual amount of light produced is the same. Due to the narrow beam used in Figure 9(B) a greater amount of illumination is produced at the object, although the object is at the same distance from the flashlight. Similarly in Figure 9(C) the radar antenna produces a wide-angle beam and only a small portion of this energy strikes the ship which represents the object in this case. However in Figure 9(D) the angle of the beam has been reduced and a greater amount of energy strikes the ship. Consequently a greater reflected signal would result in Figure 9(D) than in the case of Figure 9(C). From this explanation it should be apparent that the same object, for example the ship in Figure 9(C) or (D), can be detected at a greater distance if the radar beam has a narrow angle.

The ability to detect an object by a radar system requires that the reflected signal from that object be picked up by an antenna and amplified by the radar receiver before application to the indicating device. For a given amount of echo signal a more pronounced indication will be secured if the radar receiver is sensitive. (Sensitivity is a measure of the ability of a receiver to produce a satisfactory output from a weak input signal.) Thus, increasing the sensitivity of the radar receiver increases the ability of the receiver to handle weak reflected signals. Consequently the more sensitive the receiver is the greater will be the distance at which an object can be identified.

The maximum range at which a particular object can be detected is also affected by the terrain between the radar set and the object, and the terrain close to the object. To illustrate this point consider once more Figure 6. If the ship were close to a shore having, for example, rather steep cliffs there is a possibility that the reflection from the shoreline would mask the reflections from the ship to such an extent that the ship could not be identified.

In the case of long-range radar the curvature of the earth is the factor which limits the maximum range. Since the high frequency radio waves used in radar are reflected by the earth's surface they cannot penetrate through the earth. Also these waves travel in straight paths similar to light rays thus producing an effect referred to as a "radar horizon". This effect is illustrated in Figure 10. The illustration shows the path of the beam from the radar antenna on a ship. Any object of sufficient size located on the surface of the water or, for that matter, in the air above the surface of the water between the radar antenna and the radar horizon could be detected in this case. However, an object located at a point further from the radar antenna than the radar horizon can be detected only if a portion of the object extends above the radar horizon. For example notice that the ship at point A in Figure 10 is entirely below the radar horizon and would not be detected since the radar beam would not strike this ship. The ship at point B of Figure 10 is farther from the radar antenna than the horizon but a portion of the superstructure of this ship extends above the horizon and would be struck by the radar beam producing the reflection necessary to produce detection. The plane at point C in Figure 10 is far beyond the radar horizon but its altitude is sufficient so that the line-of-sight radar beam can strike it, thereby producing reflections.

Careful analysis of Figure 10 should reveal that there are two factors which affect the maximum range of radar installation as far as the curvature of the earth is concerned. These two factors are: (1) the height of the radar transmitting antenna and (2) the height of the object to be detected. Before proceeding with illustrations showing the manner in which the height of the antenna and objects affect the maximum range it should be mentioned that although the radio beam from a radar antenna is normally considered to follow a straight line there is a slight downward bending of the beam which occurs. This causes the radar horizon to be slightly farther away than would otherwise be expected. Under certain, very rare, conditions the bending of the beam is quite great and objects at unusually great distances can be detected.

However, this phenomenon is so rare it is of little practical value.

The actual line-of-sight distance from an elevated point to the horizon can be determined easily by the application of the formula given in Figure 11(A). It should be emphasized that due to the slight bending that normally occurs the maximum radar range under these conditions will be slightly greater. To illustrate the use of this formula let us consider an example in which the height of the radar antenna is 100 feet. The distance from the antenna to the horizon can be determined as follows:

$$D = 1.23 \times \sqrt{H}$$
$$D = 1.23 \times \sqrt{100}$$
$$D = 1.23 \times 10$$
$$D = 12.3 \text{ miles.}$$

The distance, which a radar installation could detect an object on the surface of the earth, in this case, would be slightly in excess of 12.3 miles ranging to perhaps 15 miles.

A similar computation would show that if the radar antenna were located 200 feet above the earth the distance to the horizon would be approximately 17 miles. Thus, an object on the surface of the earth could be detected by a radar set under these conditions at a maximum distance of approximately 20 miles.

Let us apply this same effect to determine the maximum distance at which a radar installation aboard an aircraft flying at 20,000 feet could detect an object on the surface of the earth.

$$D = 1.23 \times \sqrt{H}$$
$$D = 1.23 \times \sqrt{20{,}000}$$
$$D = 1.23 \times 10^2 \times \sqrt{2}$$
$$D = 1.23 \times 100 \times 1.4$$
$$D = 170 \text{ miles (approximately).}$$

Due to the bending of the radar beam the plane could actually detect an object on the surface of the earth at a distance of approximately 200 miles.

Now let us consider a situation as illustrated in Figure 11(B) where the object is located some distance above the surface of the earth. For example, the object might be an airplane. Let us assume for the sake of illustration that the height of the radar antenna is 50 feet and that the aircraft is flying at an altitude of 5000 feet. The formula which is used in this case is:

$$D = 1.23 \times (\sqrt{H} + \sqrt{A})$$
$$D = 1.23 \times (\sqrt{50} + \sqrt{5000})$$
$$D = 1.23 \times (7.1 + 71)$$
$$D = 1.23 \times 78.1$$
$$D = 97 \text{ miles.}$$

The curvature of the radar beam would permit detection of a plane at the slightly greater distance of approximately 110 miles.

Let us consider one more example to illustrate the use of this formula. Suppose the radar antenna is located at an altitude of 200 feet and the plane is flying at an altitude of 10,000 feet. The formula would then be:

$$D = 1.23 \times (\sqrt{H} + \sqrt{A})$$
$$D = 1.23 \times (\sqrt{200} + \sqrt{10,000})$$
$$D = 1.23 \times (14.1 + 100)$$
$$D = 1.23 \times 114.1$$
$$D = 140 \text{ miles (approximately).}$$

The above figure gives the actual maximum line-of-sight distance in this case but the radar distance would be slightly higher ranging to approximately 150 miles.

The foregoing computations should indicate the fact that the higher a radar antenna is located the greater will be the distance which can be covered by the radar set. It should also be evident that the higher the object is above the surface of the earth the greater is the distance at which it can be detected. For this reason planes can be detected at a much greater distance than can ships, for in very few instances does the superstructure of a ship extend more than 50 feet above the level of the ocean.

Determination of Direction and Distance

Now that we have determined the factors which affect the maximum distance at which an object can be detected by a radar set, let us determine the manner in which the direction and distance of the object can be determined. To clearly explain this phenomenon let us consider an example where sound waves can be used to determine distance and direction, as almost everyone is familiar with the echo effect produced by sound waves.

Consider Figure 12. Assume that the man shouts through the megaphone as he turns in various directions. Sound waves travel from the megaphone in the form of a beam and will strike objects in their path. In the example shown in Figure 12, when the sound waves strike the cliff they are reflected back very strongly toward the person who is shouting. Thus the person will hear an echo. The strongest echo will be heard when the megaphone is pointing directly at the cliff. If the person doing the shouting has a compass he can determine the direction of the cliff by noting the compass bearing when the echo is the strongest, or if the spot at which the person is standing has the compass bearings marked on it as illustrated in Figure 13 the direction of the cliff can easily be determined. In a similar manner the direction of the barn shown in Figure 13 could be determined by facing the megaphone in that direction, noting the point at which the maximum echo is returned and observing the calibrated compass readings for that direction. In a similar manner the direction of an object can be determined in a radar system by noticing the direction of the antenna which produces a maximum indication. In most cases the base of the antenna is calibrated in compass direction or in some cases a remote compass is employed. In either case, however, the direction of the object is indicated by maximum reflection from the object.

In the case of the situation as illustrated in Figure 12, not only can the direction of the cliff be determined but the distance from the person who is shouting to the cliff can be determined fairly accurately. This can be done by measuring the interval of time between the instant when the shout is uttered and the echo is heard. As mentioned in Assignment 1, sound travels at the rate of 1089 feet per second at sea level. However, this speed varies slightly under different altitude conditions and weather conditions and we will use the figure of 1100 feet per second for simplicity. Let us assume that two seconds of time elapse between the instant the shout occurs and the echo is heard. From the figures at hand the distance traveled by the sound waves can be easily determined. This can be done by applying the following very simple formula. Distance = Speed x Time. In this particular example:

$$D = 1100 \times 2$$
$$D = 2200 \text{ feet.}$$

Thus in the two second interval which elapses between the time of the shout and the echo, the sound waves travel a total of 2200 feet. Since the sound waves travel from the person who is shouting to the cliff and return to the "shouter", the actual distance between the person and the cliff is half this value, or 1100 feet.

To further illustrate this point let us assume that an interval of five seconds occurs between the time of the shout and the time the echo is heard. Applying the formula this becomes:

$$D = S \times T$$
$$D = 1100 \times 5$$
$$D = 5500 \text{ feet.}$$

Note that the above figure, 5500 feet, is the actual distance covered by the sound wave (from the shouter to the cliff and back to the shouter). However, our primary concern is the distance from the shouter to the cliff which is only half of the distance traveled by the sound wave. Thus the distance to the cliff in this case is 2750 feet.

In a radar system the radar wave travels from the antenna to the object where it is reflected and returned to the antenna. The speed at which the radio wave travels is known to be 186,000 miles per second and if the time of travel can be measured the distance to the object can be determined as in the preceding example. It should be obvious, however, that the time of travel from the radar set to an object and back by the radio wave will be very small due to the extremely high speed at which the radio waves travel. For this reason the time of travel of the radio waves is normally measured in millionths of a second, or as millionths of a second are normally called, microseconds, abbreviated usec. (One microsecond equals one millionth of a second.) Since radio waves travel 186,000 miles in one second it should be obvious that in one microsecond they would travel one millionth of 186,000 miles or .186 miles.

A very convenient way of using this information is to determine how many microseconds are required for a radio wave to travel one mile. This may be accomplished by dividing one by the distance traveled by the radio wave per millionth of a second. If this is done it will be found that it requires 5.375 microseconds for a radio wave to travel one mile. Similarly 10.75 microseconds of time elapse as a radio wave travels two miles, three times 5.375 or 16.125 microseconds elapse as a radio wave travels three miles, etc. This is illustrated in Figure 14. Analyze this figure carefully to make sure that you understand the relationship between the time of travel and the distance covered by the radar wave.

The primary concern in a radar system is not, however, how long it takes the radio waves to travel from the radar set to an object. Instead it is the round-trip time required for the radio wave to travel from the radar set to the object and for the reflected wave to return from the object to the radar set. This condition is illustrated in Figure 15. The rate of travel of a radio wave is the same regardless of the power present in the radio wave. The reflected wave from the objective travels back toward the radar transmitter at the same speed as the wave travels when leaving the radar transmitter or 186,000 miles per second. Thus if the object is one mile from the transmitter the round-trip time will be 5.375 microseconds (time traveling to the object) plus 5.375 microseconds (time for echo to return to radar set), or a total of 10.75 microseconds. Similarly if the object is two miles from the radar transmitter the round-trip time will be 2 x 10.75 microseconds or 21.5 microseconds. Notice that the round-trip time is the important time interval to remember in connection with the radar system and the figure of 10.75 microseconds per mile round-trip time should be remembered. For example, if the object is a plane ten miles away the round-trip time for the radar wave would be 107.5 microseconds and if the objective were a high-flying plane one hundred miles away, the time between the transmitted pulse and the return echo would be 1075 microseconds.

Why the Radar Signal is Transmitted in the Form of Pulses

Past experience with sound should illustrate to the Associate that the best results are obtained when dealing with echos if the brief sound is used rather than a long sound. For example, if the system illustrated in Figure 12 or 13 were being used to determine the direction of a cliff the best results would be obtained if a very brief hello were shouted rather than a long drawn-out hello. The reason for this is the fact that if a long drawn-out hello is called, the echo may return before the shout is completed. Thus the shout would cover up the echo and it could not be distinguished. However, if the call is very brief, it will be finished before the echo returns and the direction can be determined very simply. The same condition is true in a radar system. If the energy were transmitted from the radar antenna constantly, the weak reflected signal could not be detected when it returned and the radar system would be useless. Instead, the energy is transmitted for a very brief period and then a period of non-transmission results. During this period when no energy is being transmitted, the radio wave has sufficient time to travel to an objective and be reflected, returning to the radar antenna. Since the transmitter is not operating and the receiver is quite sensitive, this returning pulse can be detected, thus indicating that an object has been struck by the radar wave. For this reason the radar waves are always transmitted in the form of pulses. The length of the pulses varies with the different types of radar sets which are designed for different applications and also the number of pulses transmitted per second varies. In the different types of radar installations the length of the pulses range from 1/4 microsecond to 30 microseconds and the number of pulses transmitted per second range from 200 to approximately 5000 pulses per second.

There are three factors which remain to be explained in this basic explanation of a radar system. These are: (1) The effects of the pulse length on a radar system and the reason why different pulse lengths are used in different types of radar installations. (NOTE: Pulse width is often used in place of the term pulse length.) (2) The importance of the number of pulses per second in a radar system. (3) The manner in which a radar indicator is able to measure the time interval between the transmitted pulse and the echo pulse, considering the fact that this is only in the order of a few millionths of a second. The first two of these items will be dealt with in detail at this time. The third will be explained briefly. Later in the training program after cathode-ray tubes have been considered in detail, this subject can be explained more thoroughly.

In the previous explanation, the various factors which affect the maximum range of a radar set were outlined. The minimum range of a radar set is determined by the pulse length. The shorter the pulse the closer will be the minimum range of a radar system. The term minimum range means the minimum distance at which an object can be correctly located. For this reason it should be apparent that in a radar installation designed for use in locating objects at great distances, a relatively long pulse (several microseconds) may be used. However, in radar systems which are used to locate objects which are close, for example, in a radar installation used to aid in the navigation of a ship, a very short pulse length will be used so that objects close to the ship can be accurately located.

Since the radio wave requires 5.375 microseconds to travel one mile, in one microsecond the radar wave will travel 1/5 of a mile, or approximately 1000 feet. Bearing this fact in mind analyze the series of events depicted in Figure 16. Illustration A of this figure shows a radar equipped ship one mile from an object which is shown to be a rock in this particular case. At this instant the radar transmitter is just beginning to send out a pulse of radio frequency energy which travels away from the antenna at the speed of light, approximately 1000 feet per microsecond. Illustration B of this figure shows the conditions which exist if the pulse length is one microsecond. In this case the first energy transmitted during the pulse has traveled 1000 feet and this "bunch" or packet of radio frequency energy occupies a space 1000 feet in length. Since it is assumed that the pulse length in this particular case is one microsecond, the transmitter is turned off at this instant. However, the radio frequency energy which has been transmitted continues to move away from the ship at the speed of light and after an additional one microsecond has elapsed a condition as illustrated in Figure 16(C) is produced. The "packet" of radar energy has now moved approximately 1000 feet from the antenna, but since the transmitter is now turned off no further energy is being transmitted.

Figure 16(D) illustrates the fact that after a total of 5.375 microseconds has elapsed from the time of the start of the pulse the "front edge" of the packet of radio waves just reaches the obstacle. A portion of the energy is reflected back toward the radar antenna and the remaining portion of the radio frequency energy continues on as illustrated in Figure 16(E). The reflected energy is still in the form of a bunch or packet of radio waves and returns toward the ship at the speed of light as illustrated in Figure 16(F). Since the distance to be covered is one mile, 5.375 microseconds of time elapses between the instant the reflection occurs and the instant the returning wave reaches the radar antenna on the ship. Thus a total of 10.75 microseconds of time elapses during the entire process depicted in Figure 16. Since the transmitter was not again turned on after the initial pulse was transmitted, the receiver would be able to detect the echo signal and the time which elapsed between the time of the transmitted pulse and the echo pulse could be measured on the indicating device. This could, in turn, be converted into distance, indicating that the rock was one mile from the ship. This would be a very satisfactory radar system and the presence of the rock would be indicated in sufficient time to permit correct navigation.

Let us now use the same radar installation to illustrate the fact that the one microsecond pulse duration is too great if the radar installation is to indicate the presence of close obstacles, for example, an obstacle 400 feet from the ship such as might be encountered when navigating a narrow channel. This condition is illustrated in Figure 17. As in Figure 16, the illustration labeled A shows the condition at the start of the transmitted pulse. Figure 17(B) illustrates a condition 1/4 microsecond after the start of the pulse. Notice that in this case the "front edge" of the wave packet has progressed to a point more than half-way to the obstacle. In Figure 17(C) the condition which occurs 1/2 microsecond after the start of the pulse is illustrated and it can be seen that reflection is occurring from the rock and that the transmitter is still generating a pulse. Since a pulse length of one microsecond is employed the condition which is illustrated in Figure 17(D) occurs when the time is still slightly less than one microsecond from the start of the pulse. Notice that although the pulse is still being transmitted the echo has arrived at the transmitter. Under these conditions the signal arriving at the receiver from the transmitter is so strong that the pulse will not be detected at this time at all. Even at the time of one microsecond as illustrated in Figure 17(E) a similar condition is still occurring. After this instant the transmitter is cut off and a very small portion of the reflected pulse follows. However, this portion of the energy is quite small and since a small amount of time is required for the receiver to recover from the effect of the strong pulse applied to it during transmission of the radar signal, no indication of the reflected signal will be received on the indicator.

After analyzing Figure 17 the question may arise, how is it possible for a radar system to indicate objects which are close at hand. The answer to this question is: Close objects can be detected through the use of very short radar pulses. For example, if radar pulses of 1/4 of a microsecond in length are employed in an instance as shown in Figure 17, the presence of the object can be detected since the transmitter will have been turned off for an appreciable time before the reflected pulse returns to the radar set. Expanding this reasoning it should be apparent that pulse lengths of several microseconds can be employed when objects are to be detected at great distances.

From the foregoing a general conclusion can be drawn. If the radar installation is to indicate objects close at hand short pulses will be employed whereas longer pulses may be employed in indicating objects at great distances.

The use of a short pulse has one other advantage. This is the fact that adjacent objects can be separated to a better degree with a short pulse. If the radar transmitter uses pulses of one microsecond duration, objects must be at least 500 feet apart to give separate indications. Thus if a radar installation is being used to detect the presence of aircraft, and a group of aircraft is approaching, a single indication will be given if a one microsecond pulse is employed and the planes are less than 500 feet apart. However, if the planes are more than 500 feet apart separate indications will be given and the number of planes can be determined. If, however, a shorter length pulse is employed separate indications will be obtained if the planes are closer together. For example if a 1/4 microsecond pulse is used separate indications can be obtained if the objects are more than 125 feet apart. With this arrangement the number of planes or other objects such as ships in a group can be more easily determined by means of radar.

Let us now consider the pulse repetition rate or in other words the number of pulses transmitted per second in a radar installation. If only one radar pulse strikes an object and is reflected back to the radar set, the energy returned will be a very minute value of energy and will not be sufficient to produce an indication on the radar indicator. Consequently the transmitted pulses in a radar installation are repeated at regular intervals, that is, the pulse is transmitted and then a period of non-transmission occurs. (The period of "silence" must be sufficiently long for the echo to return to the transmitter.) Then another pulse is transmitted and followed by a period of non-transmission. A careful analysis of the foregoing explanation concerning the time required for the round-trip travel of the radar signal should indicate that the time interval between pulses, or in other words the number of pulses per second, is determined by the maximum distance to be covered by a radar set. For example let us assume that a radar set is being used to detect planes at the maximum distance of 200 miles. (Of course the planes would have to be flying at altitudes in excess of 20,000 feet to be detected at this distance.) Under these conditions the round-trip time of the radar wave would be 200 x 10.75 or 2150 microseconds. As illustrated previously the next pulse should not be transmitted until this echo has returned, thus an interval of at least 2150 microseconds should occur between pulses. To determine the number of pulses and intervals of the required length which can be produced in a second it is only necessary to divide 1,000,000 by 2150 which gives a figure of 465 pulses per second. Note that this is the maximum number of pulses that could be employed and most radar installations do not use the maximum pulse repetition rate. Instead, in such instance, a pulse repetition rate of approximately 250 pulses per second would probably be employed. In radar installations which are intended primarily for detecting objects at closer ranges, the round-trip time of the signal will be smaller, therefore the interval between pulses can be less, and higher pulse repetition rates may be employed.

It should be emphasized that aside from the fact that one reflected radar pulse produces only a very minute amount of energy as mentioned previously there is another decided advantage to the use of many pulses per second in a radar installation. This is the fact that such an arrangement permits the indication of the radar set to "follow" a moving object. For example, as an object approaches the radar installation the indicator will reveal the fact that the distance to the object is becoming gradually less. There are two advantages gained by this. Not only does this arrangement permit the radar operator to determine at all times the exact position of the object, but it also enables him to identify the object to a certain degree. To illustrate: the indication secured for a low flying aircraft or a ship might be practically identical on the radar indicator. However, be observing the speed at which the object is moving as indicated on the radar indicator, the operator can determine whether the object is a plane or a ship.

The Radar Beam Elevation and Rotation

If a person were sitting in a boat in the middle of a lake at night and wished to determine whether or not there were any islands located nearby, he could do so by shining a powerful searchlight along the surface of the lake and swing the beam of the light around a complete circle or 360 degrees. A similar arrangement may be used in a radar set if it is desired to detect objects on the surface of the earth. Such an arrangement is employed for example in the case of naval vessels with the radar equipment designed to detect other surface vessels. If however the person sitting in the boat wished to determine whether or not there were any bats flying around he would not only have to swing the searchlight beam in a 360 degree arc around the boat but would also have to elevate the beam. That is the air near the surface of the water would have to be searched as would the air at higher angles of elevation. In the case of a radar installation there are two ways in which this can be done. One of these is to use a beam which is very broad in the vertical direction so that altitudes ranging from slightly above the earth to approximately 50,000 feet are covered by this beam at a distance of

100 to 150 miles. If such a wide beam is used however the radar set cannot indicate the altitude of the plane. Figure 18 shows a method which can be used to search the desired altitudes with a narrow radar beam. The mechanical mechanism which rotates the radar beam around the 360 degree circle also gradually increases the tilt of the antenna as the antenna is rotated. The result is that the beam at any particular distance from the transmitter is slightly higher on each revolution, or in other words, effectively the tip of the beam is spiraling upward. In this manner the air surrounding the radar set can be scanned completely and any object present can be indicated.

In some installations it is not necessary for the radar equipment to search all of the area around the unit. For example a radar installation along the seashore may be used only for the purpose of searching for planes approaching from the sea. In this case the antenna equipment is modified so that the antenna moves back and forth through the desired angle of rotation to search a required sector. Such an arrangement is often called sector scanning.

The width of the beam used by the different types of radar sets varies. In general it can be stated that the wider the radar beam, the greater is the area covered by the beam and therefore the more easy it is to detect an object. However, the more narrow the beam is, the more accurate a particular object can be located. This can be understood very easily by comparing the effect obtained with a flashlight. If there is an object to be located with the light it can be located much more easily if the angle of the flashlight beam is wide, provided of course the beam intensity under these conditions is still sufficient to illuminate the object. However if the flashlight were to be used to "locate" the object, that is, indicate its direction in degrees and its elevation, it should be apparent that a narrow beam would provide a much more accurate indication. The same is true in radar installations.

Figure 19 shows a radar antenna installation on the pilot boat New Jersey which operates out of New York harbor. This antenna can be rotated so that the radar beam covers the required area.

In connection with the rotation of the radar beam and its vertical movement, there are two terms which are used. These are azimuth and elevation. The term azimuth indicates the angular measurement of the object from North. For example if an object is located due east of the radar set the azimuth would be 90 degrees. The term elevation indicates the angle at which the radar antenna is "tipped" from it's normal position. For example in the case of ground radar installation, if an object is located when the radar beam is at an angle of 30 degrees with the earth surface, the elevation is 30 degrees. In many radar installations automatic computers are incorporated so that when the distance to an object is known and the elevation is obtained, the altitude at which a plane is flying may be automatically computed.

Measuring the Distance to an Object by Measuring the Time Interval Between the Transmitted Pulse and Returned Echo.

As pointed out, the time between a transmitted radar pulse and echo pulse is a very minute quantity; so minute, in fact, that it would seem impossible to measure this small interval. In any mechanical clock arrangement it is indeed impossible to measure these intervals of a few millionths of a second. However, electronic circuits in conjunction with cathode-ray tubes can be used very conveniently to measure such time intervals. To understand exactly how this is possible will require an understanding of the operation of cathode-ray tubes which will be dealt with at a later point in the training program. However, a very basic explanation will suffice at this point.

The cathode-ray tubes which are used in radar indicators are quite similar to the picture tubes which are used in television receivers. The inside surface of the face of the cathode-ray tube (The face of the tube is the end with the large diameter.) is coated with a fluorescent material and when the electronic circuits associated with the cathode-ray tube cause a beam of electrons to strike this surface, a glowing spot will appear. As other electronic circuits cause the electron beam to move, this spot will trace a visible line across the screen of the cathode-ray tube as illustrated in Figure 20(A). This glowing line, called the trace, is moved across the screen of the cathode-ray tube at a uniform rate by the associated electronic circuits. That is, if ten microseconds are required for the beam to move from the left edge of the screen one inch toward the right, ten more microseconds will be required for the next one inch motion of the beam and so forth. When the cathode-ray tube and its associated circuits are used in conjunction with a radar transmitter the trace obtained on the screen is somewhat as illustrated in Figure 20(B). When the pulse from the transmitter occurs the rectangular pulse is produced on the glowing line. Notice that this is a large pulse as the high powered transmitter is very close to the receiver and the r-f energy which enters the receiver under this condition is quite high. After the transmitter is turned off the glowing line continues across the screen at a uniform rate as illustrated in Figure 20(A). When the echo pulse returns to the radar set another smaller rectangular pulse or "pip", as it is often called, is produced in the trace.

As mentioned previously a time of 10.75 microseconds corresponds to one mile round-trip between the occurrence of the transmitted pulse and echo. Let us assume in the example of Figure 20(B) that was determined by checking a calibrated dial on the indicator that it took exactly 215 microseconds for the trace of Figure 20(B) to be produced on the indicator cathode-ray tube. It would be possible under these conditions to lay a scale across the face of the tube as shown and thereby measure the position of "pips" on the trace in terms of time. In Figure 20(B), since 215 microseconds are required for the entire trace to be produced only half of this value of 107.5 microseconds elapse as the spot moves from the left edge of the trace to the center. For sake of convenience the echo pulse is shown at this point. Through this means it can be determined that the echo pulse occurs 107.5 microseconds after the transmitted pulse. Since the round-trip time of a radar pulse is 10.75 microseconds per mile, the 107.5 microseconds delay between the transmitted pulse and the echo in Figure 20 indicates that the object is ten miles from the radar transmitter. It would be simpler therefore to mark the scale in miles as shown rather than in time and read the distance directly in miles.

Although a scale could be used to measure this distance as illustrated in Figure 20(B), in normal cases such a system is not used because variations in voltage in the radar circuits may cause the glowing line or trace, to move about on the screen of the cathode-ray tube. Consequently the scale cannot be maintained in a fixed position. Instead of using an external scale, marker pulses or range pulses are normally used in conjunction with the trace. This condition is illustrated in Figure 21. The electronic circuits associated with the indicator time these range pulses very accurately so that they are spaced at a definite distance or range from each other. For example in Figure 21 the electronic circuits time these pulses at intervals of 107.5 microseconds apart on the trace. This time is equal to the round-trip time for the radar waves if the object is ten miles from the radar set. Thus these pulses are effectively "10 miles apart" on the trace. It is only necessary to observe the relationship of the echo pulses with respect to the range pulses to determine the distance of the object or objects producing the deflection. For example in Figure 21 the first echo shown would indicate an object at about 25 miles (note a range pulse occurs at the start of the transmitted pulse but cannot be seen). Similarly the second echo occurs from an object approximately 42 miles from the radar set whereas the third echo is produced by an object approximately 57 miles from the radar set. Thus it can be seen that the presence of the range pulses enables the radar operator to determine the position of objects to a fairly high degree of accuracy.

Most radar installations incorporate a range selector switch so that the length of time required to produce the line across the face of the cathode-ray tube (this line is often called the time base) can be set at several values. When this switch is changed the marker pulses are usually changed also. For example in the illustration shown in Figure 21 the switch would be in such a position that the time base would represent 70 miles with 10 mile markers or range pulses. If it were desirable to obtain the accurate range on an object less than 10 miles from the transmitter the radar set would probably incorporate a 10 mile range position. When the switch is placed in this position the time required to produce the entire time base would be 107.5 microseconds and 10.75 microsecond range pulses would be inserted as shown in Figure 22. Thus each one of these range pulses would represent a distance of one mile and if the display as indicated in Figure 22 were obtained it would indicate that one object was approximately 3 1/2 miles from the transmitter and another was approximately 7.7 miles from the transmitter. Thus by shortening the time base the accuracy at which close objects can be located is improved.

In radar installations where a large number of echo pulses would be received from objects it is very difficult to identify each of the objects and to keep track of them. In such instances the indicator arrangement is such that a map of the surrounding area is plotted. Such an indicator is normally called a plan-position-indicator (abbreviated P-P-I). Plan-position-indicators are normally employed in radar installations aboard ship for use when navigating near shore. Figure 23 shows a plan-position-indicator installed aboard a commercial liner. Plan-position-indicators are also employed in airborne radar installations used for bombing as well as in commercial aircraft to enable the observation of the terrain over which the plane is flying.

In a commercial application, a radar set may be installed at a port. In this case a plan-position-indicator is employed and the radar installation may be used as an aid to piloting ships approaching or leaving the harbor when visibility is limited. The position of incoming ships can be determined and the pilot boats can be guided to the incoming ships by means of radio instructions. Figure 24 illustrates such an application of radar. At the left of this figure is shown a chart of the harbor at the port of Long Beach, California. The radar site is indicated and the shoreline, breakwater, etc., can be seen. At the right of this figure is shown the plan-position-indicator view of the same area. Notice that the position of the breakwater is again clearly discernable, as is the shoreline. The small white dots appearing in the harbor are ships or buoys.

Summary

In a radar system pulses of high frequency radio energy are produced by the transmitter and radiated into space by a special, highly directional antenna. These pulses of radio energy travel away from the antenna at the speed of light, in a straight path. As the radio waves strike various objects, part of the energy is reflected, and a portion of this reflected energy travels back to the radar antenna. At this point the reflected signal, or echo, is "picked up" and applied to the radar receiver which amplifies it many times. The signal is then applied to the radar indicator. Since the radio waves travel at a constant rate, it is possible to determine the distance, which the objects causing the echo, is from the radar antenna by measuring the total time between the instant the pulse is transmitted and when the echo returns. This action is accomplished in the radar indicator. The direction of the object producing the reflection can be determined by the antenna position because the maximum reflected signal results when the antenna is aimed directly at an object.

The foregoing discussion should provide the Associate with an understanding of the underlying principles of radar. This discussion is of course, in no way complete since the manner in which the various circuits operate has not been considered. As the Associate advances through the training program, however, special assignments will be included at appropriate points explaining the operation of the various radar circuits.

TEST QUESTIONS

Use the enclosed answer sheet to send in your answers to this assignment.

The questions on this test are of the multiple-choice type. In each case four answers will be given, one of which is the correct answer, except in cases where two answers are required, as indicated. To indicate your choice of the correct answer, mark out the letter opposite the question number on the answer sheet which corresponds to the correct answer. For example, if you feel that answer (A) is correct for question No. 1, indicate your preference on the answer sheet as follows:

1. ~~(A)~~ (B) (C) (D)

Send in your answers to this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. The strongest radar echo would be obtained from:
   (A) An object underground.
   (B) An object near the surface of the sea.
   X (C) An object near the transmitter.
   (D) An object far away from the transmitter.

2. The maximum range of a radar set is: (CHECK TWO)
   X (A) Increased by raising the antenna height.
   (B) Greater if the object to be detected is at a high altitude.
   (C) Increased by lowering the antenna height.
   (D) Greater if the object to be detected is at a low altitude.

3. What is the line-of-sight distance between a radar antenna 200 feet above the ground and a plane traveling at an altitude of 5000 feet?
   (A) 1,000,000 feet
   X (B) Approximately 104 miles
   (C) Approximately 25 miles
   (D) Approximately 85 miles

4. One microsecond is:
   (A) 1000 seconds
   (B) 1,000,000 seconds
   (C) one thousandth of a second
   X (D) one millionth of a second

5. What is the total time in microseconds required for a radar wave to travel from the antenna to an object one mile away, and for the reflected wave to travel back to the radar antenna?
   (A) 1 microsecond
   X (B) 10.75 microseconds
   (C) 53.75 microseconds
   (D) 2 microseconds

6. If a radar installation is to identify objects close to the radar set:
   (A) The pulse length makes no difference.
   (B) The pulse length should be long.
 X (C) The pulse length should be short.
   (D) The pulse should be on the order of 10 microseconds in length.

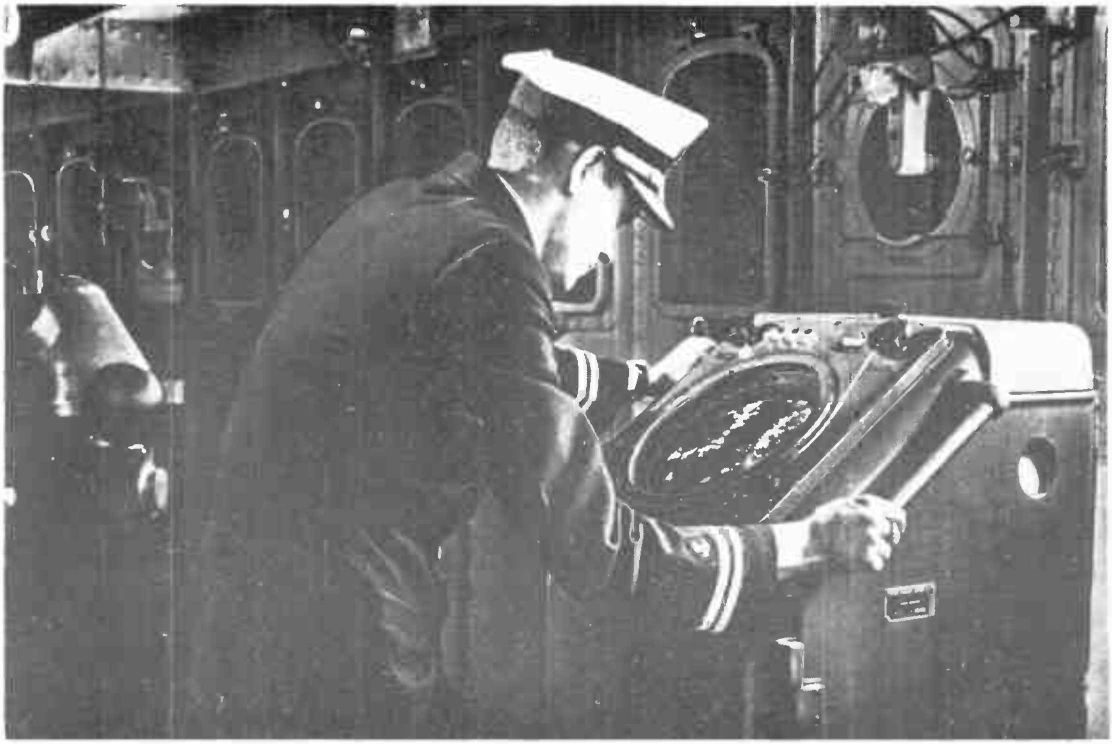
7. The term azimuth means:
 X (A) The angular measurement of the object from North.
   (B) The angle at which the radar antenna is "tipped," with respect to the earth's surface.
   (C) The number of pulses per second.
   (D) The pulse length.

8. The purpose of range pulses is to:
   (A) Enable the radar operator to determine the distance of objects to a fairly high degree of accuracy.
   (B) Enable the radar operator to determine the azimuth of an object.
   (C) Enable the radar operator to determine the elevation of an object.
   (D) Enable the radar operator to determine the pulse length.

9. A radar indicator which effectively plots a map or chart of the area surrounding the radar set is called:
   (A) Round-about-indicator.
 X (B) Plan-position-indicator.
   (C) Map-chart-indicator.
   (D) Azimuth-range-indicator.

10. Basically, radar works upon the principle that:
   (A) Almost every object radiates radio waves which can be picked up by a radar receiver.
   (B) Almost every object reflects radio waves, and these reflected waves can be picked up by a radar receiver.
   (C) Almost every object radiates high frequency sound waves which can be picked up by an electronic "ear."
   (D) Any television receiver can be used as a radar indicator.

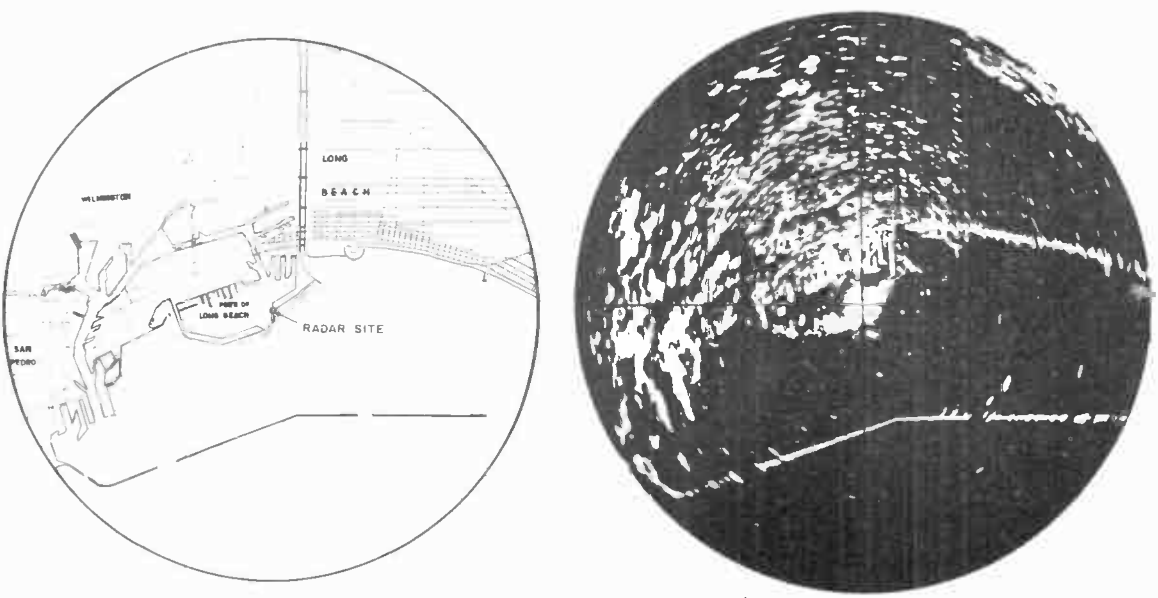
PLAN POSITION INDICATOR ON GRACE LINES, SANTA PAULA



(Courtesy SPERRY GYROSCOPE Co.)

FIGURE 23

CHART AND PPI RADAR VIEW OF PORT OF LONG BEACH, CAL.



(Courtesy SPERRY GYROSCOPE Co.)

FIGURE 24

RADAR ANTENNA INSTALLATION

(Courtesy SPERRY GYROSCOPE Co.)

FIGURE 19

DETERMINING DIRECTION WITH SOUND WAVES

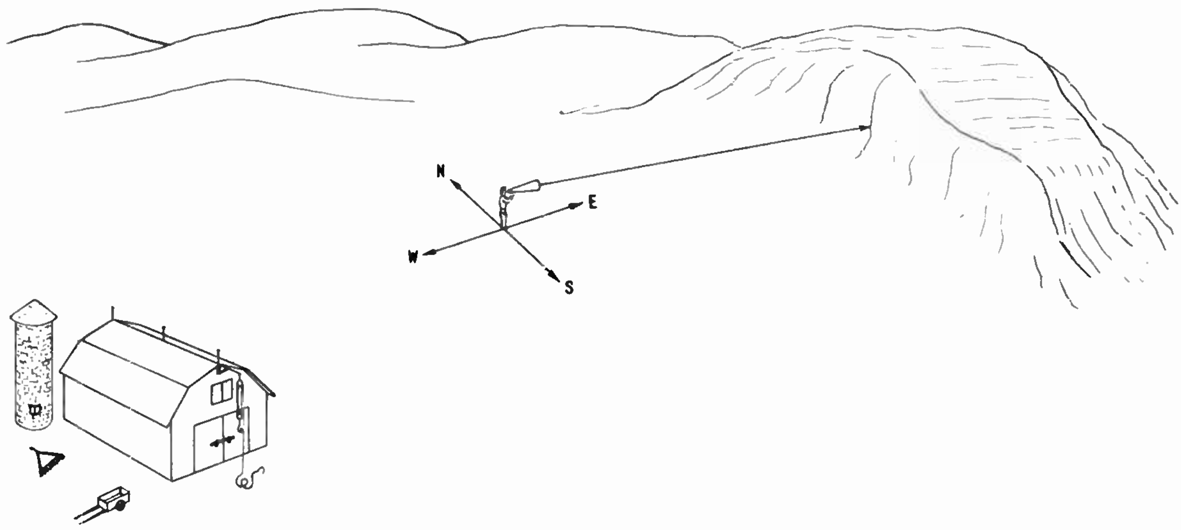


FIGURE 13

RELATIONSHIP BETWEEN TIME AND DISTANCE TRAVELED BY A RADAR WAVE

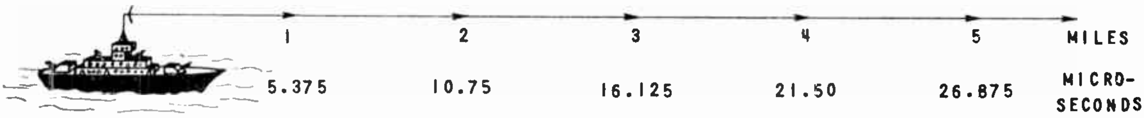
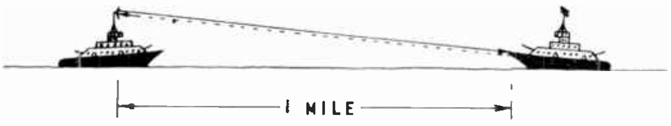


FIGURE 14

ROUND-TRIP TIME FOR A RADAR SIGNAL



TIME INTERVAL BETWEEN INSTANT RADAR WAVE IS TRANSMITTED AND INSTANT ECHO RETURNS TO RADAR SET IS EQUAL TO TIME REQUIRED FOR WAVE TO TRAVEL FROM RADAR ANTENNA TO OBJECTIVE, *PLUS* TIME REQUIRED FOR ECHO TO RETURN TO RADAR SET. IN THIS EXAMPLE THIS IS 5.375 μSEC. + 5.375 μSEC.; OR, 10.75 μSEC.

FIGURE 15

REFLECTION OF RADAR WAVES FROM TERRAIN

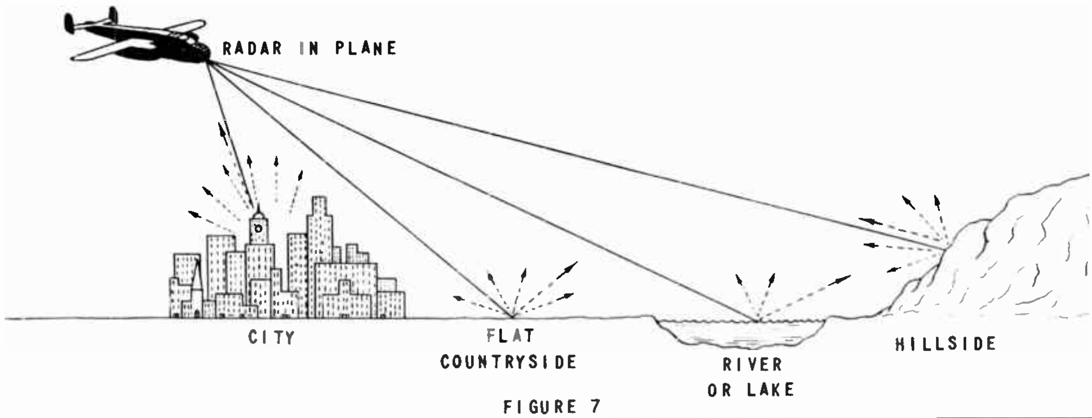


FIGURE 7

COMPARING EFFECT OF DISTANCE IN CASE OF LIGHT AND RADAR

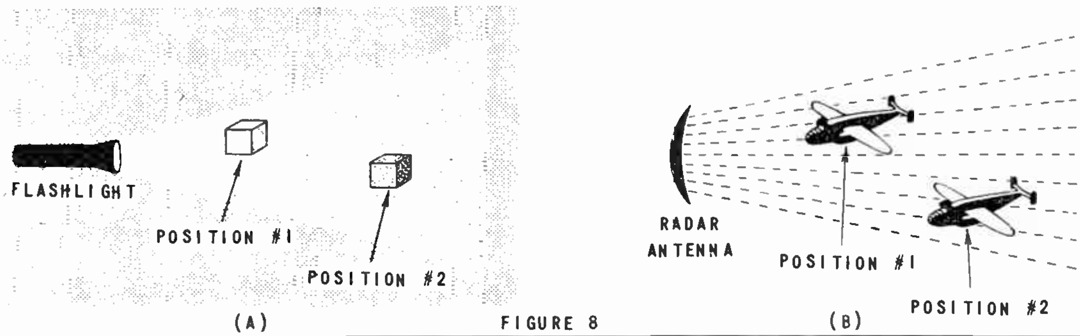


FIGURE 8

EFFECT OF BEAM WIDTH ON ILLUMINATION AND RADAR

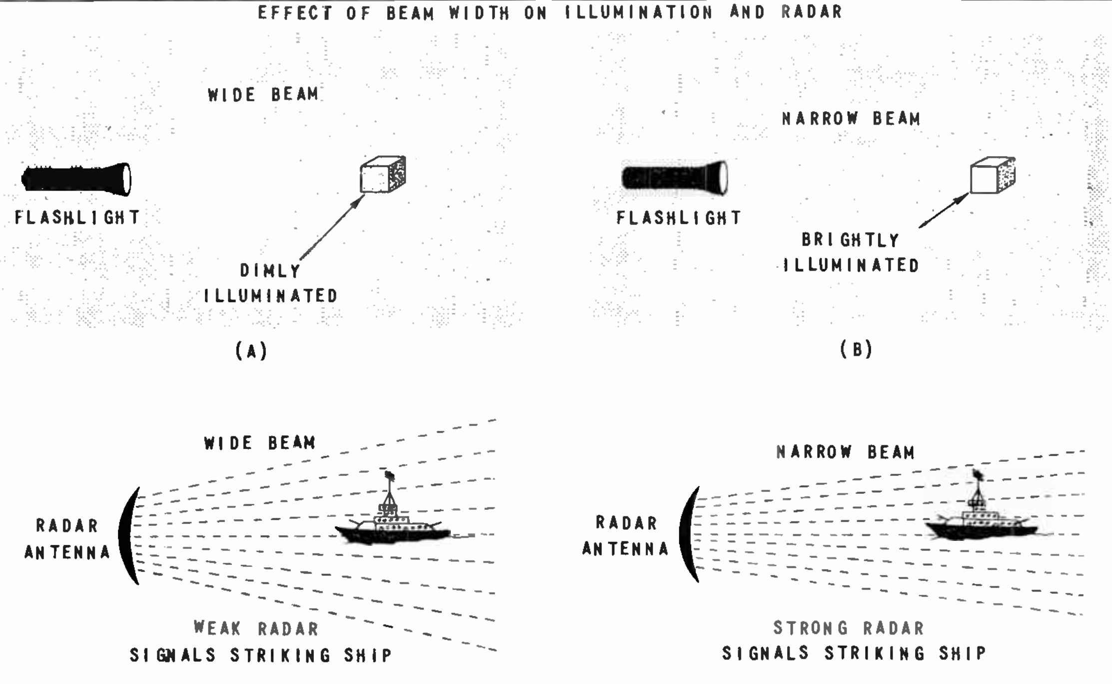


FIGURE 9

NATURE'S RADAR SYSTEM

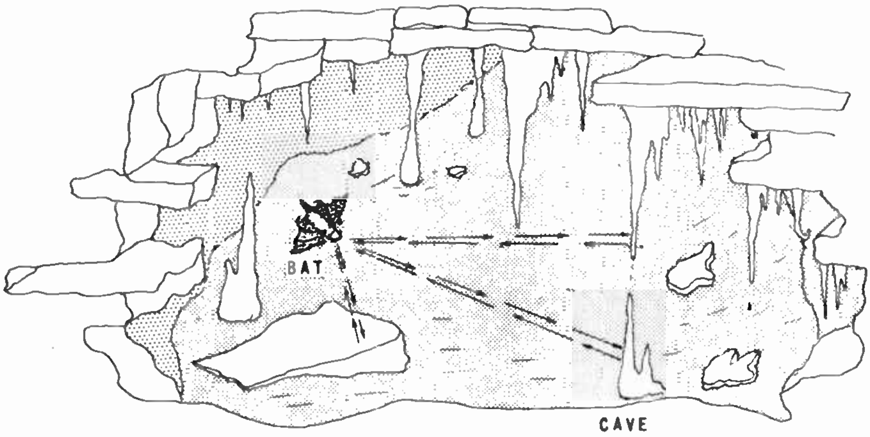


FIGURE 1

FUNDAMENTALS OF A RADAR SYSTEM

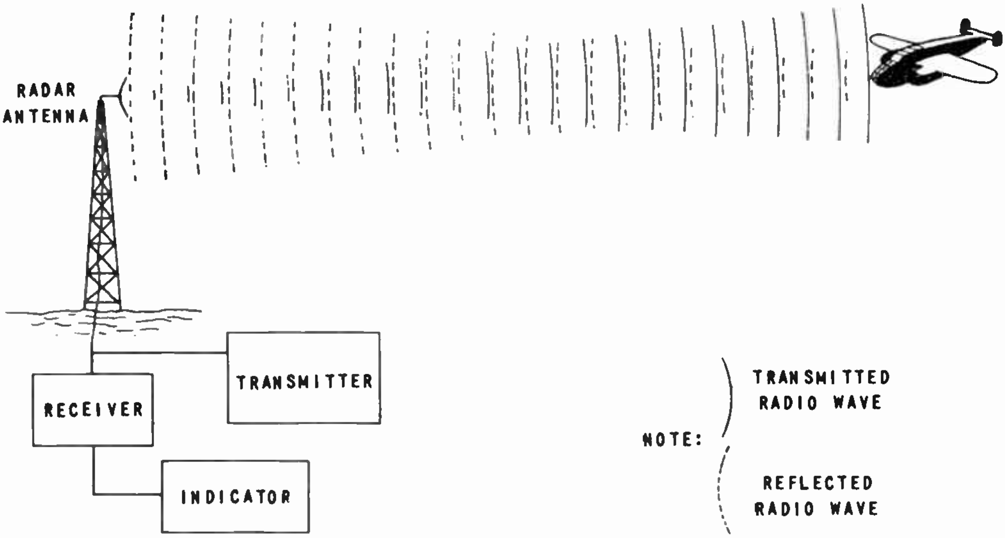


FIGURE 2

COMPARISON OF THE REFLECTION OF LIGHT RAYS AND RADIO WAVES

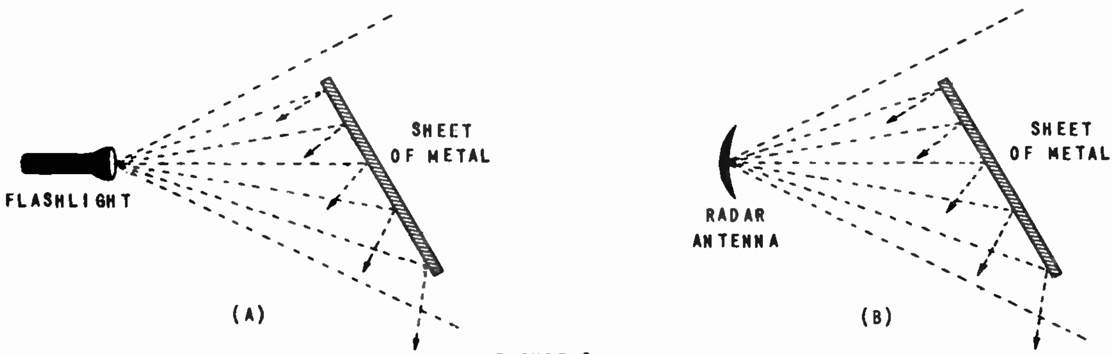


FIGURE 3