PRACTICAL RADIO CIRCUITS

No. 4FR

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FOREWORD

I want to tell you about Student .... He wrote me sometime ago saying that he had completed something like fifteen lessons in the course and was still unable to repair receivers satisfactorily. He asked me to advise him where his trouble lay.

I devoted practically one whole morning to his problem, for if a student comes to me for advice as to his progress, I certainly want to give him all the help I can.

To make a long story short, I looked up his record and went over all his correspondence with the Institute and here is what I found—when this student was studying simple receiving circuits, he sent in one letter after another to the Institute, requesting information on transmitting apparatus, television apparatus, everything in fact except simple receiving circuits. And that's the way it was all through his course—his mind was way ahead of his work—his head was in the clouds most of the time.

Now you know as well as I do what his trouble was—he wasn't digging into his lessons in the proper spirit. To get the benefit of each lesson, the student must exhaust the possibilities in that lesson and he must devote all his energies to that one lesson. Of course questions arise in your mind, many of which anticipate subjects which will be taken up in later lessons and it is a great temptation to write to me for answers to these questions. Personally, I like to answer questions of any sort and I used to feel that if a student asked rather advanced questions that it showed real interest in Radio. But I have been convinced that a man learning Radio in his spare time must put everything out of his mind, as far as Radio is concerned, but the lesson he is working on at the time.

Keep your feet on the ground. Study each lesson thoroughly, understand it thoroughly. If there are any questions on the lesson that you can't answer for yourself no matter how hard you try, then write to me and I'll be glad to help you. As for related questions or advanced questions, save them. They will be answered in later texts just when that particular information will be of most value to you.

Do each day's work thoroughly—leave tomorrow's work for tomorrow.

J. E. SMITH.

Practical Radio Circuits

SIMPLE CIRCUITS

In previous lessons, when we studied the production and some of the actions of electricity, we met the word "circuit" several times. Whenever we speak about electricity in action, that is current, we must speak about circuits—for current will act only when in a circuit.

Radio-Tricians speak in terms of circuits—you might hear one mention a tuned radio frequency circuit, or a superheterodyne circuit, or the circuit diagram of some particular receiver. Very obviously, it is important that we get a clear idea of what we mean by a Radio circuit.

The word itself is very clearly connected with the word "circle." In fact, both of them are taken from the same Latin word, which peculiarly enough is the same as our English word "circus." The Roman "circus" was the track on which chariot races were held. Our modern circus takes its name from the fact that in the main tent there is always a track on which some of the performance is held, usually races of some sort or other.

A circle is an unbroken ring—and a circuit is an unbroken path over which electrons can flow. The main point of comparison between a circuit and a circle is that both must be unbroken, that is, complete, before they are rightly called a circuit or a circle. However, an electrical or Radio circuit need not be circular in form, the chief requirement being that a circuit provides a complete path for moving electrons, that is, current flow.

Having spoken about current flowing in a circuit, we can see that one essential part of any circuit is a source of e.m.f. But the whole purpose of a circuit is to get the e.m.f. supplied by the source to do some useful work—therefore another essential part of a circuit is the "load," the device in which electrical energy is converted into some other kind of energy, and made use of. To connect the load and source of e.m.f., there are conducting wires which complete the circuit.

Thus in the circuit shown in Fig. 1, the dry cell is the source of e.m.f., and the light bulb is the load. And this is a good

example of a fundamental electrical circuit. It is shown schematically in Fig. 2.

The switch shown in Figs. 1 and 2 is provided so that there will be a means of opening and closing the circuit without the necessity of disconnecting either the dry cell or the lamp. You remember that a single break in a circuit will prevent current from flowing in it—a switch as shown, placed anywhere in the circuit provides an effective control—when opened, the current will not flow and the lamp will not light—when closed, the circuit is complete, current will flow and the lamp will light.

It is important to remember that the switch can be in any part of the circuit—it could be anywhere in the left conducting wire, as well as any place in the right conducting wire.

The source of supply may be one or more dry cells, a storage battery, a generator, in fact, any kind of generating device, or the source of supply may be a wall or panel socket, as in the case of a house lighting system where the immediate source of supply for an individual light, for example, is the house line, which connects ultimately to the generators in the power house.
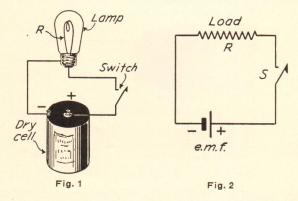
The load in the circuit may be an electric bell, a light bulb, an electric motor, a coffee percolator, a vacuum tube or a complete Radio set. In the simple circuit shown in Fig. 1, the load is, of course, the lamp which is a means of converting electrical energy supplied by the dry cell into light energy. The light is incidental to the conversion into heat energy as you possibly know, but it is the light we are interested in because that is what we make use of. This simple circuit is interesting to us as Radio-Tricians because it is very similar to the filament circuit in a Radio receiver, but in this case we are interested in heat, rather than light, for filament heat is necessary for the operation of vacuum tubes.

You will want to know now, how electrical energy is converted into heat energy in an electric light bulb or in a vacuum tube. Referring again to Fig. 1, "R," in the center of the lamp, is a very fine carbon or Tungsten wire, having high resistance. In a previous lesson it was mentioned that the effect of resistance in an electrical circuit was to slow down current flow, because electrons can't pass through a resistance readily, and the electrons becoming violently agitated, bump against each other with terrific speed, causing the resistance to become hot. When metal is white hot it glows brightly. Put this hot metal into a vacuum, as it is in a light bulb, and the result is an intense bright light.

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If an electric motor is the load in our circuit, it is the means of converting electrical energy into mechanical energy which is motion. If a toaster is the load, electrical energy is converted into heat. And the same is true if the load is an electric stove.

From this simple, fundamental circuit all sorts of complicated circuits arise. Look at a diagram of a Radio circuit, it may seem extremely complicated. But there is this cheering thought, that no matter how complex a circuit may be, it can always be divided up into fundamental circuits—and there will always be a source of e.m.f., conducting wires, and one or more loads in each.

We shall go on to consider slightly more complex circuits, building up our knowledge gradually, so that by the time you finish this lesson, even the diagram of a complex modern super-
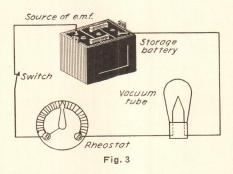

Fig. 1   Fig. 2

heterodyne "circuit" will mean much more to you than a maze of lines and symbols.

As you learned in the last lesson, several dry cells may be connected either in series or in parallel to form the source of e.m.f. In the same way, the load in the circuit may consist of several parts, or as we more commonly say, there may be several loads in the circuit. These loads may be connected either in series or in parallel in the same manner as several dry cells would be connected together. But no matter how many parts there are to the source, or how many parts the load has, the thing to remember is that they must all be connected together so that there can be a continuous path for the current through each dry cell and through each load.

Very naturally, when we add a second load to a circuit, the electrical energy in that circuit is going to be divided between

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the two loads. If we were to put another light in series with the light in Fig. 1, both lights would glow with less brilliancy than one light alone in the circuit. Now if it were desired to reduce the brilliancy of one light in a circuit without putting another light in the circuit, how could it be done? Very clearly, it could be done by putting some other load in the circuit, one which would not produce light. Of course you know what we would use for this second load—some form of resistance. And if we want to have a control over the brilliance of the lamp, so that we can make it glow dimly or brightly at will, we place in the circuit, in series with the lamp, a variable resistance.

Now refer to Fig. 3 where we have a vacuum tube filament circuit. This is very much like our first circuit—it has a source of e.m.f., conducting wires, a load (the filament of the vacuum tube), and in addition to these three essentials we have a switch
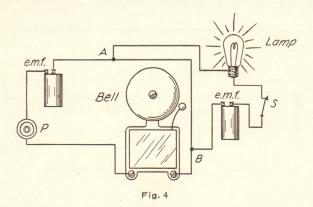

Fig. 3

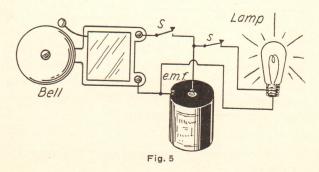which is an on-off control, and a variable resistance, which we call a rheostat.

This resistance is a second load in the circuit, and as it is variable we can adjust the amount of energy it will take away from the filament. The arm of the rheostat can be rotated over the high resistance winding so as to include more or less of it in the circuit. When the arm points to the right, very little of the resistance is included in the circuit and most of the current will flow through the filament. But as the arm is moved to the left, more resistance is included in the circuit and more of the electrical energy in the circuit is used up in the resistance, taking energy away from the filament.

Our rheostat may well be compared to a faucet in a plumbing system—opening the faucet wide allows a great deal of water to flow from it, but as the faucet is closed, less and less water will flow.

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So far we have not changed our fundamental circuit very much—we have merely added a control. Now look at Fig. 4. A bit more complex, it is true, but you have no difficulty in analyzing it. What do we have? We have two circuits, each of which has its source of e.m.f., its load, and its controlling device. But they are not two distinct circuits because both make use of that

Fig. 4

portion of the conducting wire between A and B. We see that conductor AB is common to both circuits. But even though this is the case here, each circuit will function independently, the one will have no effect at all on the other. The fact that two circuits can have one conducting wire in common, is made use of in power
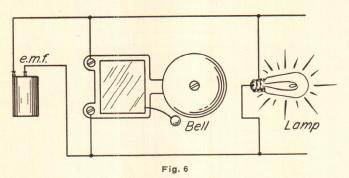

Fig. 5

transmission where the output of two generators is transmitted by what is known as the three wire system, one of them being common to both circuits.
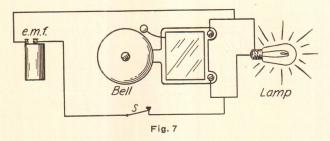
And here in Fig. 4 we have our first introduction to an electrical network. In Radio we hear much about networks of one kind or another as for example, broadcasting networks—and

our receiver circuit should properly be called a network for it is made up of many circuits which have much in common as we shall see.

In Fig. 5 we have another type of network. In this case the source of e.m.f. is common to both circuits. As there is a separate switch for each circuit, each load is independent of the other and both circuits can be made to operate simultaneously or

Fig. 6

individually at will. Examine this circuit carefully. Are the loads connected in series or in parallel? The electrical equivalent of this circuit is shown in Fig. 6. Now we can see that the loads are in parallel. Notice, however, that in this equivalent circuit, the transmission lines are shown as common to both loads. In this respect it differs from the circuit in Fig. 5, where each cir-

Fig. 7

cuit has its own conducting wire and only the source of e.m.f. is common to both circuits.

Figure 7 shows a parallel arrangement of loads connected to a common source through common transmission lines. We can look at the circuit in Fig. 7 in two ways—the first as a double circuit having a common source of e.m.f. and common transmission lines; second, we could consider it as a network of three circuits, one being the source of e.m.f., the transmission lines

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and the double load, and the other two being the individual loads and their circuits including the conducting wires up to the point where they meet the common transmission lines. In this case, we must consider the source of e.m.f. for each load as the ends of the wire to which connection with the load is made.

This is practically what we do when we consider a wall socket as a source of e.m.f. Of course, the ultimate source is the generator in the power house, but the immediate source is the transmission lines in the house which are brought out at the wall socket.

Now we come to a simple network which is part of the complete network of a Radio receiver. In Fig. 8 is shown how vacuum tube filaments are connected in parallel, that is, as parallel loads, to a battery source of supply. Figure 9 shows the same parallel connection of the filaments in an A.C. set in which
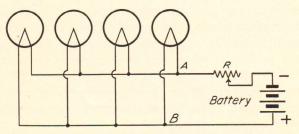

Fig. 8—Four Vacuum Tube Filament Circuits Connected in Parallel.

the source of supply is another circuit, through the transformer. Notice that in Fig. 8 there is a rheostat connected *in series* with the source of supply. In this sort of circuit the rheostat will control the current flowing through all the tubes and varying the adjustment of the rheostat will cause all the tubes to burn more brightly or more dimly simultaneously.

This is really a parallel-series circuit. The rheostat must be considered a load and this part is in series. The rest of the load, the filaments, is in parallel. In a series circuit the electrical energy is divided between the loads. Thus increasing the resistance of the rheostat, will take away energy from the filaments.

We can trace through this circuit and see why this should be. In tracing through circuits we can start at either side of the source of e.m.f. and the result will always be the same. It is, however, customary to trace from the positive to negative because until very recently it was thought that electricity flowed

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from positive to negative. Even today there are some scientists who insist that current flows from positive to negative, even though they admit that electron flow is from negative to positive. This confusion won't disturb us at all if we realize that circuits can be traced either way. Starting at the positive pole of the battery in Fig. 8 and tracing through the circuit we can see that all the current from the source will have to pass through and divide between filaments before it reaches the rheostat. Tracing through from the negative to positive we observe that all the current must pass through the resistance before passing through the filaments. It doesn't make any difference which we consider the correct procedure—the effect is always the same, that is, the rheostat provides a control over all the current flowing in the filaments.
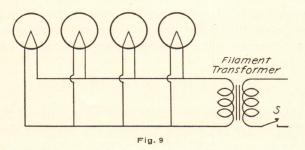
Now let us suppose that the rheostat is set to a mid-position, meaning that just half its resistance is included in the circuit, and that the filaments are glowing normally. What will happen if we place another tube in the circuit in parallel? All the tubes will become dim—we have increased the load. But if we adjust the rheostat so that it offers less resistance to current flow we can bring all the filaments up to normal brilliancy. What we are really doing is re-distributing the energy in the circuit, decreasing part of the load (the rheostat load) to compensate for the added load of another filament.

In a Radio receiver anywhere from three to five circuits meet at the vacuum tube. In later lessons we shall study each of these circuits by itself, the plate circuit, the grid circuit, the screen grid circuit in the case of screen grid tubes, and two screen grid circuits in the Pentode. This may seem difficult at first sight—and it is true that a complete Radio circuit is by no means a simple matter—but if you bear in mind that no matter how complicated any network is, it can be resolved into simple circuits, each of which has its load, its source of e.m.f. and its connecting wires, we shall never have any trouble getting the full significance of a Radio "circuit" diagram.

There is just one more thing we must consider before we leave these very simple circuits. Look at Fig. 8 again. Suppose a metal bar or a piece of bare wire fell across the connecting point A and B. What would happen? Naturally a path would be provided for current flow through the resistance and through A and B back to the source of e.m.f. And current would flow along this path because current always takes the shortest path.

What would happen to the filaments? They wouldn't light at all. The current would be side-tracked and kept away from the filaments, and the circuit would be "shorted." This then, would be a short circuit, about which you have probably heard many times. And short circuits are a frequent cause of trouble in Radio circuits—many times in your work as a Radio-Trician it will be necessary for you to track down short circuits and remove their cause so that current can flow over the proper path.

In any kind of electrical or Radio circuit, great care must be exercised to prevent the possibility of shorting. Conducting wires are insulated, oftentimes electrical and Radio apparatus must be mounted on non-conducting material, many types of insulators are in use to keep the current in the proper path so there will be no "short" either within the circuit or between one circuit and an adjacent circuit.

Fig. 9

The word insulate also is taken from the language of the old Romans. Their word "insula" meant island, a body of land surrounded entirely by water. A wire is insulated when it is surrounded entirely by non-conducting material. A piece of Radio apparatus is insulated when it is entirely surrounded by non-conducting material.

CONDUCTORS AND INSULATORS

All substances, natural or manufactured, can be divided for electrical purposes into three classes—conductors, resistors and insulators. Conductors are so-called because current can flow in them easily. Current will flow in resistors but not quite so easily, it will be held back. For practical purposes we say that current cannot flow at all through insulating material although this is true only up to a certain point, for a too high voltage will cause an insulator to break down and become a conductor.

Between these three groups there are no hard and fast dividing lines. However, engineers arbitrarily list various substances in the various groups, depending on the ease with which they conduct electricity.

Under the first group the following substances are considered to fall: Silver, copper, aluminum, zinc, brass, platinum, iron, nickel, tin, lead, in fact nearly all metals.

The substances classed as resistors are: German silver, carbon, graphite, nichrome, and various metallic alloys.

The insulators are: Slate, porcelain, bakelite, dry wood, glass, silk, cotton, rubber, mica, dry air, in fact, most non-metallic materials.

But don't forget, however, that no material is a perfect conductor and no material is a perfect insulator. Even the best conductors known offer some resistance to current flow. On the other hand, even such good insulators as glass, mica, and porcelain break down, if called upon to handle too high an e.m.f. However, below this point, which is known as the break-down point, insulators are for all practical purposes, non-conductors.

RESISTANCE IN CONDUCTORS

An electrical conductor may well be compared to a water pipe. When water is flowing through the pipe, its flow will be hindered to some extent by friction, that is, the inner walls of the pipe offer some frictional resistance to the flow of water through it. If these walls are rough, the friction will be considerable and the resistance to water flow will be high. If these walls are smooth, the resistance will be less, but some will be there all the same and we can't eliminate it.

A large pipe will offer less resistance to water flow than a small pipe—and if too high a pressure is exerted on a small pipe, it will burst. The longer the pipe, the greater will be the loss in pressure through the pipe.

So too, an electrical conductor offers some resistance to current flow and this resistance is greater in a small wire, less in a larger wire, and varies with the length of the wire.

What happens to the energy that is lost because of resistance in a water pipe? It may seem peculiar, but the energy that is lost is converted into heat energy and dissipated. The amount of heat generated in a water system is so small that it is inappreciable, but in an electrical circuit, the heat generated by a

resistance can be considerable. In fact, as previously mentioned, it is this heat that is made use of in electrical cooking devices. But in an ordinary conductor where it is desired to keep resistance to a minimum, there is energy lost in heat and you may notice that some conductors which are designed to carry very heavy current have asbestos insulation so that the heat generated cannot do any harm.

A large wire can carry heavier current than a small wire. If too heavy a current is passed through a small wire, it will become excessively hot even to the point of melting.

A simple example will bring home to us very forcibly the effect of length of conductors on power loss. A man in New York speaking to a friend in San Francisco might think he is on a single circuit, the conductors of which connect him and the Pacific Coast. If this were the case, it would mean that there would be six thousand miles of wire, and all the resistance in six thousand miles of wire would have to be overcome by the current carrying his voice. But this resistance is so high that if there were only one circuit, the amount of power required to transmit a voice across the country would be so great as to be commercially impossible. How is it done then? Every fifty miles or so there is a sub-station where the voice is amplified several hundred times, in the same manner as sound signals are amplified in our Radio receiver. Were it not for these amplifying stations and the fact that the voice is amplified hundreds of times on its way across the country, trans-continental telephone service would be an impossibility. At the bottom of all this, the necessity for so much amplification, is the fact that copper, our most commonly used conductor of electrical current, has considerable resistance.

Silver offers slightly less resistance to current flow than copper, but of course it would be impractical to use silver wires in general electrical and Radio work, due to its cost.

From what has been said about copper wire as a conductor of electricity, it is clear that the size of the wire to be used for any particular purpose is important. If made too small, energy will be lost in heat—and if there is too much heat generated to be dissipated rapidly enough, the wire will melt and the circuit will be opened. On the other hand, if we make the wire too large, that is larger than necessary, we are wasting copper. Therefore, the size of wire depends largely on the amount of current it will be called on to carry.

Wire sizes are designated by numbers which correspond to numbers on a standard gauge. Of course, wire sizes could be given in thousandths of an inch but it has been found that the use of a certain number to designate a certain size wire simplifies matters a great deal. A standard wire gauge is the B & S Gauge, named after the Brown and Sharp Tool Manufacturing Company. This is sometimes called the "American Wire Gauge." Details of wire gauges and wire tables will be given in a later lesson text.

When considering various materials of which conductors and resistors are made, it is customary to talk about their resistance as compared to the resistance of copper. In other words, copper is used as a standard and the resistance of any
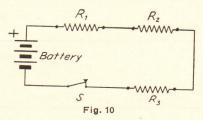
TABLE NO. 1

Conductor	Relative Resistance (as compared with copper)
Silver	0.92
Copper	1.00
Aluminum	1.67
Zinc	3.60
Iron	6.17
Nickel	7.72
Steel	8.62
German Silver	17.30

other metal is given as being so many times that of copper. Of course in doing this we must assume that the metals we are considering are of the same shape, form and size. The wire used for the filament rheostat in Fig. 8 to regulate the amount of current flow in the circuit has many times the resistance of a copper wire, the same size and same length. Considering copper as the starting point, that is, 1, iron wire will have a certain number of times more resistance than copper, as will steel, German silver, and wires of other metals. For example, German silver has 17.3 times as much resistance as copper; an aluminum wire will have 1.67 times as much resistance as copper. A table is given above in which the relative resistances of various metals are given, using copper as the standard.

CHARACTERISTICS OF SERIES CIRCUITS

We are well acquainted with the word series as it is used in general life. The World Series is a *succession* of baseball games to decide the championship. A series of numbers is a succession of numbers. In Radio when we speak of series circuits, we mean the arrangement of apparatus in succession, one after the other, in such a way that the current must flow through one before it flows through the others. In series circuits, if one part is defective and current can't pass through it, the entire circuit is opened. And this is the chief characteristic of series circuits— every part in that circuit is dependent on the other parts and every part must be intact, current must go through it, otherwise current cannot flow in the circuit.

Figure 10 shows a closed series circuit consisting of three cells connected in series with three resistances, R_1, R_2 and R_3 and a switch (S). The cells are connected in series—the positive

Fig. 10

terminal of each cell is joined with the negative terminal of the next cell in the series. As you learned in a previous lesson, the total e.m.f. acting in this circuit with the switch closed will be the sum of the e.m.f.'s of the individual cells.
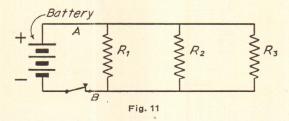
The total resistance of the three resistance loads in series is the sum of the individual resistances, that is $R_1 + R_2 + R_3$.

CHARACTERISTICS OF PARALLEL CIRCUITS

Sources of e.m.f. are said to be connected in parallel when their positive terminals are joined to one conductor and their negative terminals to the other. Parallel connections of dry cells were shown in the previous lesson text. Another way of describing a parallel connection of dry cells is to say that all their positive poles are connected together and all their negative poles are connected together.

When loads are connected in parallel, each carries only part of the total current. Instead of having one main circuit as in a series circuit, in parallel circuits we have one main circuit and

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various branches, each branch having a current of its own taken from the main circuit. In parallel circuits it is not necessary that current flow in each branch to have current flowing in the main circuit. In a parallel connection of lights, one light may be burnt out but still the other lights would light. In a series connection of lights, if one is burnt out, the whole circuit is dead.

Now let us take the parts used in Fig. 10 and connect them in parallel. See Fig. 11 which shows how this parallel circuit would look. You can trace through this circuit and follow the current as it flows from the battery, starting either at the negative pole or the positive pole, it doesn't make any difference. Some of the current will flow through R_1, some through R_2 and some through R_3. If R_1 were broken, current would still flow through R_2 and R_3 as can easily be seen. But with R_1, R_2 and R_3 in the circuit, will the total resistance be $R_1 + R_2 + R_3$? Not at all. In fact, the more resistances we have in parallel, the more current will flow through the main circuit A and B.

Fig. 11

The total resistance in the circuit will be considerably less than the sum of the three resistances because the current has more paths to travel over than if the resistances were connected in series.
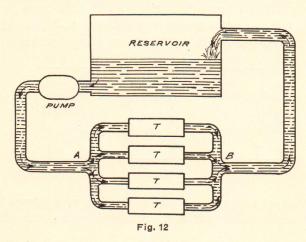
The water system shown in Fig. 12 will help to make clear the action of loads in parallel. The branches marked T correspond with the resistances in our former example. Notice that the branches are pipes of smaller diameter than the main pipe and so can really be called water resistances. But as these are connected in parallel as shown, altogether they will not offer much resistance to water flow. If there were only one it might hold back the water considerably. But as there are four in parallel, there are four paths for the water to flow through which it manages to do very easily.

Now returning to Fig. 11, trace through it again. It is apparent that the same amount of current won't flow through every point in that circuit. It divides between the branches and

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the amount that flows in each branch depends, as you will learn in the next lesson, on the amount of resistance in it.

We can carry our discussion of this circuit one step farther, and anticipate what we are going to learn in the next lesson. The total resistance in the circuit is less than the value of the smallest resistance in parallel. Furthermore, the current in each branch is less than the total current since the sum of the currents in all the branches is equal to the total current. See if you can't figure this out from the water analysis shown in Fig. 12.

Most practical electrical circuits are combinations of series and parallel, known as the series-parallel, or parallel-series circuits. In fact, the current shown in Fig. 8 is really a series-
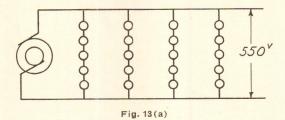

Fig. 12

parallel circuit—the source of e.m.f. and rheostat are connected in series and the loads in parallel.

A series-parallel arrangement is usually used where it is desired to operate a number of similar electrical devices, such as lamps or motors, from a line, the voltage of which is several times that required to operate a single lamp or motor. For example, a series-parallel circuit is used in the light wiring of street cars. Here the source of supply is generally 550 volts, therefore five 110-volt lamps of similar current carrying capacity are connected in series across the circuit and groups of five connected in parallel as shown in Fig. 13(a). From what you have learned about series circuits you know the great disadvantage of this arrangement—if any lamp in a series group burns out, the remaining lamps in that series group will not light. You will

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see later that this is exactly the same procedure employed in D.C. socket powered receivers, where the filaments are connected in series.

Some of this may seem rather far from Radio, but the Radio-Trician should know considerable about the simple problems of general electricity. A large portion of Radio receivers receive their operating current from city lines and the Radio-Trician must make sure, not only that the receiver is connected properly to the source of supply but that the proper voltage is being obtained for best operation. A fundamental knowledge of electrical wiring often enables Radio-Tricians to prevent serious damage to Radio receivers or other electrical apparatus.

It is never wise to connect any piece of apparatus to a source of supply until you know that the voltage and current requirements are met. For example, electricity for lighting purposes within a radius of about a mile from a generating station is

Fig. 13(a)

generally direct current. A Radio-Trician who knows his business will never allow an A.C. receiver to be connected to a D.C. line.
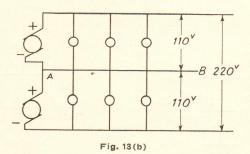
Current supplied by a generating station to most electric light circuits is ordinarily alternating current and of course, the Radio-Trician who knows his electricity would not try to operate a D.C. receiver from alternating current, or for that matter any piece of apparatus which was designed for D.C. operation.

Before leaving the subject of electrical power systems, it will be well to consider briefly an ordinary three-wire transmission system. You may have noticed three wires entering a house and you may have wondered why there were three wires instead of two. As previously mentioned, one wire is common so that in a three-wire system we really have two circuits each of which uses a common return wire. This common wire is often called the neutral wire.

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It was also mentioned that in a system of this sort the output of two generators is carried. Thus we can get 110 volts across either of the outer wires and the neutral wire. Across both outside wires we would get the output of both generators which would be 220 volts. See Fig. 13 (b).

This is of importance to Radio-Tricians—they must understand this fact about three-wire systems so that they will never connect a 110-volt receiver across the outer lines, as 220 volts applied to a 110-volt receiver would burn it out completely.

It is clear from what was said about the resistance of conductors why three-wire systems are used. Aside from the fact that 220 volts may be required for some types of apparatus, the three-wire system allows double the amount of current to be carried in the most economical manner. For large homes, where a great deal of current is drawn from the lines, if only a two-
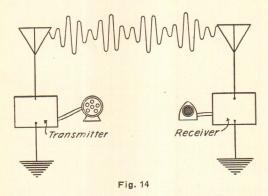

Fig. 13(b)

wire system were used the wires would have to be extremely large to handle the heavy current drain. But by the use of three wires the same amount of current can be hauled using only one extra wire of ordinary size. The use of the neutral wire which is common to tube circuits results in a great saving of copper.

RADIO CIRCUITS

Now that we have laid the groundwork, having gotten a good knowledge of fundamental electrical circuits, we can go on to consider simple Radio circuits. Look at Fig. 14 which shows the complete transmitting and receiving network in outline form. The illustration is largely self-explanatory. Radio energy is sent out from the transmitting aerial and is picked up by the receiving aerial. Do we have one complete circuit? No, for the transmitter is not directly connected to the receiver. What we have

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is a *chain* of circuits one feeding into the other in order. Just as in our telephone line we have a boosting action as we proceed from coast to coast. The transmitter connects with the receiver by sending out Radio waves which the latter intercepts and passes through its various circuits. This then is strictly a case of networks, and clearly a *chain* network.

Now let us forget for the moment, the transmitter and consider the receiver network itself—for in Radio we have networks within networks and circuits within circuits. And at the present time we are interested chiefly in receivers. Figure 15 shows a simple, fundamental Radio circuit, of the most elementary type. Here we have nothing but an aerial, a crystal detector, a pair of headphones and a ground connection. It doesn't look much like a closed circuit and yet it really is one as shown by the dotted
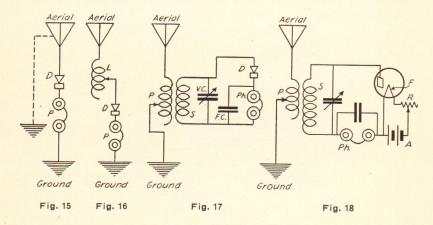

Fig. 14

line. There is no visible connection between the aerial and ground other than through the receiving apparatus, but it is there just the same or current could not flow in it. Just what this unseen connection is we shall have to leave until later.

Tracing through this circuit is a very simple matter—and for practical purposes it doesn't matter whether we start at the ground or at the aerial. Let us, however, start with the aerial and trace the incoming signal through the circuit. The Radio wave striking the aerial becomes a very small electrical current which flows through the detector "D" where it is changed to audio frequency current, then it flows through the earphones "P" causing the diaphragm of them to vibrate and produce sounds, the same sounds that were impressed on the microphone in the transmitting station. The current flows through the phones into the ground.

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Notice that current must flow through each part of the circuit—if there were a break in any point in this circuit the current could not flow. Therefore it is a series circuit—the detector and earphones are in series with the antenna and ground.

Figure 16 shows the same circuit but has included in it a tuning coil, marked "L" which acts as a station selector. Of course these very simple circuits are not efficient—they won't pick up signals from stations more than a few miles away. The untuned circuit shown in Fig. 15 will respond to signals of several stations if equally powerful and at an equal distance from the receiver. The circuit in Fig. 16 can be tuned, but only to nearby powerful stations.
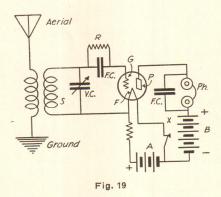
When we come to Fig. 17 we have what should properly be

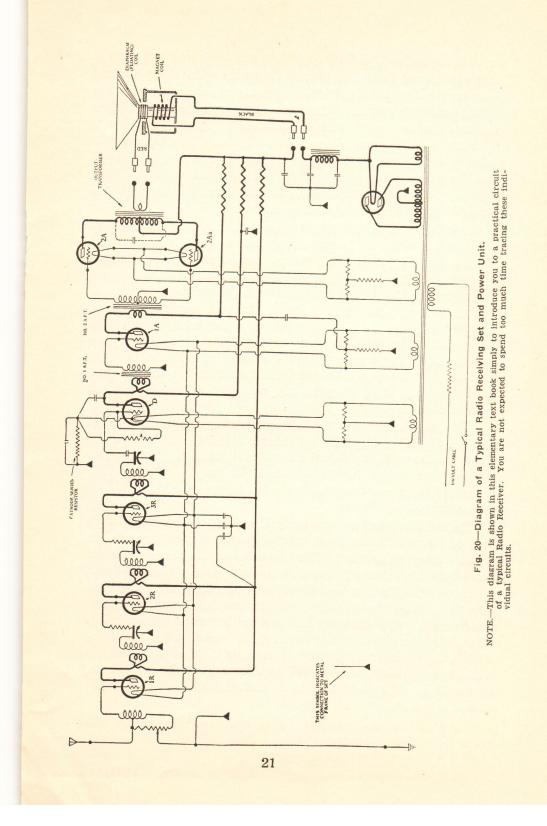Fig. 15   Fig. 16   Fig. 17   Fig. 18

called a receiving network, for here we have two circuits. In the antenna circuit there is a coil in series with the aerial and ground. The other circuit is a series-parallel circuit—notice the crystal detector "D" and the earphones "Ph" in series. In this circuit the source of supply is "S," a coil. The two coils marked "P" and "S" are the primary and secondary of a transformer by means of which energy is passed on from the aerial circuit to the second circuit. Just how energy can be passed from one coil to another is another matter which we must leave until later. For the present, however, we must consider "S" as the source of supply in the second circuit. The load in the circuit consists of the detector and the phones. The variable condenser, in parallel with "S" is a tuning device. It regulates current flow as would a resistance, in that it adjusts its resis-

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tance so that the circuit responds to only one of the various broadcasting stations. To the other stations it acts like a short circuit.

Figure 18 shows practically the same circuit except that in place of the crystal detector we have a simple two-element vacuum tube. You will notice that in the preceding circuits, the source of supply was primarily the antenna—no batteries were needed. But just as soon as we put a vacuum tube in a circuit, we must use a local source of supply to operate the vacuum tube. We have spoken about the necessity of heating the filament of a vacuum tube—we have studied a filament circuit in detail. Here you can see it in a practical application. Trace through the filament circuit—F-R-A. Then notice that the filament is common to two circuits—it is in the RA circuit and also in series with the phones.

Fig. 19

Now we're beginning to get to the point we started out for. Look at Fig. 19. Look at the vacuum tube—a regular 3-element vacuum tube—the grid "G" at the left, the filament "F" in the center and the plate "P" shown at the right. Our circuit is beginning to look like something. In this tube we have three circuits meeting, the filament circuit, the grid circuit and the plate circuit. We can easily trace each of these circuits by this time. Let us start with the filament circuit because we are already so familiar with filament circuits. Starting at A+, or A—, it really doesn't make a bit of difference, we trace through F, X and A. The A battery heats the filament and that's all it does. The filament is common to both filament circuit and plate circuit as it was in the previous circuit and we can trace the plate circuit through the phones, "Ph," through the "B" bat-

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Fig. 20—Diagram of a Typical Radio Receiving Set and Power Unit.

NOTE.—This diagram is shown in this elementary text book simply to introduce you to a practical circuit of a typical Radio Receiver. You are not expected to spend too much time tracing these individual circuits.

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tery, through point "X," through "F" and back to "P."* In the plate circuit we have the phones in series with the plate and B battery. Notice the fixed condenser connected across the phones—really a parallel connection, or as we sometimes say the condenser is "in shunt" with the phones.

Now for the grid circuit—starting at "S," through "R" and a fixed condenser, through "G," through F and back to S. And the variable condenser "VC" in parallel with "S," the secondary of the transformer, has the same function as the variable condenser in previous circuits.

Tracing through circuits isn't a bit difficult, is it, provided you remember that in every simple circuit there is a source of e.m.f., a load and connecting wires. Of course there are many questions which come into your mind at this point as to the use of various parts in these circuits, but don't allow them to distract your mind from your present work. All your questions will be answered in time. Right now you are preparing yourself to understand the answers to all these questions, so devote all your energies to getting a clear mental picture of the things brought up in this lesson—everything that isn't clear at the present time about the function of the grid, for example, in this circuit will be made clear to you very shortly.

We are ready now to look at a diagram of a typical receiver. Refer to Fig. 20. Of course, it looks complicated, but if you isolate each individual circuit and trace it through, you will be surprised to learn how easily it can be resolved into various sections, each of which has its source of e.m.f., its load and its connecting wires.
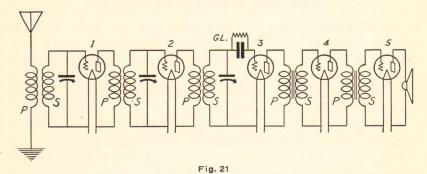
Figure 21 shows substantially the same circuit stripped of some of its parts so that we can follow the signal through the circuit with greater ease. The source of signal current for the receiver is the antenna, and this current flows in the antenna circuit as was brought out previously. Energy is transferred from the aerial circuit to the first vacuum tube circuit and here it is boosted, stepped up, by the first radio frequency amplifier. Then the source of supply for the first R.F. stage is the secondary of the transformer marked S, the variable condenser in parallel with the secondary is a control used to adjust the circuit for signals from a particular station, and the load of the circuit

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*Later we will learn that there are circuits through the vacuum tube even if there are no conducting wires.

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consists of the vacuum tube and the primary of the second transformer.

In the second R.F. stage, the source of e.m.f. is the secondary of the second transformer and the load consists of the second tube and the primary of the third transformer. The same is true for each succeeding circuit. In the third stage, the presence of the grid leak, GL, causes the tube to act as a detector which serves to convert the radio frequency current into current of audio frequency and at the same time give it a slight boost. The last stage, the output stage, is shown as a single tube stage but in the complete diagram this is shown as a 2-tube stage, the two tubes being arranged in push-pull.

Go over the complete circuit carefully, Fig. 20, trace each individual circuit through to the best of your ability. Don't bother about the cathode series resistor in the detector stage or

Fig. 21

the push-pull arrangement as these will be explained in detail later on in the course. Notice that the plate circuit is shown with darker lines than the other circuits which will make it easy for you to trace them through. Just one hint—the question will probably arise in your mind regarding the return conductor of the plate circuit. As it is shown, there is only one conductor, the plate supply—how then can the plate circuit be complete? You remember that when we were considering Fig. 18 it was mentioned that the filament is common to both filament circuit and the plate circuit. Therefore, it should be apparent that there must be some direct connection between the plate circuit and the filament circuit. If you study the supply system shown at the lower right-hand portion of the diagram, you will see that the plate supply is grounded and that the filament supply is also grounded. It is this ground that provides the connection

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between the plate and filament circuits and so the plate circuit is completed through the ground connection.

There is one more thing that might cause you a little trouble —the output of the rectifier tube, the tube having two plates shown in the lower right-hand corner, goes through a choke coil, then it goes through the magnet coil of the speaker before going through the plates of the other tubes. If the speaker is disconnected as shown, there can be no plate current in the receiver.

You are urged to make a careful study of the diagram in Fig. 20. The ability to trace circuits from diagrams or in a receiver is an important part of the Radio-Trician's equipment. Become accustomed to doing it now and it will make your study of Radio a good deal easier and enable you to start servicing receivers soon.

ELECTRICAL MEASUREMENTS

In practical electricity and in Radio we have units of measurement just as in every day life we have the units, foot, yard, mile, quart and ounce. Some of these have already been mentioned, such as the "volt"—the unit of electrical force—the "ampere," the unit of current flow; and the coulomb, the quantity of electricity; the "ohm," the unit of electrical resistance.

The pressure (voltage) and the "quantity per second" (in amperes) in a circuit can easily be determined by the use of meters (measuring devices). The "voltmeter" measures the voltages, the "ammeter" (ampere-meter) measures the current flowing. Knowing the value of the e.m.f. and the current, a Radio-Trician can make many of the calculations needed in his work—he can determine the resistance in the circuit, he can determine with the use of a voltmeter and an ammeter just where the trouble is in defective sets or what steps he must take to improve a set.
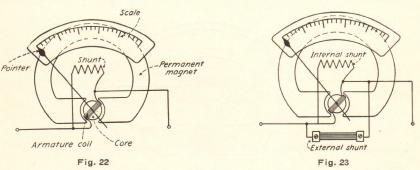
THE D. C. AMMETER

The voltmeter and the ammeter both employ principles with which you already are familiar, namely, those of magnetic attraction. Figure 22 shows the internal construction of an ammeter in sketch form. The particular meter shown is a milli-ammeter. The rectangular coil of wire is mounted over a stationary iron core, on a shaft fitted in bearings at each end so that it is free to rotate in a magnetic field produced by a permanent magnet. The armature assembly (coil on shaft) is held

in position by pivots at the top and bottom of the shaft. To the shaft is connected a pointer which moves over a graduated scale. Springs are so arranged that they hold the pointer to a zero position on the scale.

The armature of an ammeter is a small load, which is placed in series with the main load R in a circuit. A very small part of the energy passing through the circuit is converted into magnetic energy in the coil. The armature coil of an ammeter or milli-ammeter has very little resistance so it should not be connected across a source of e.m.f. without an extra load to limit the current to the safe carrying capacity of the size of wire used in the coil.
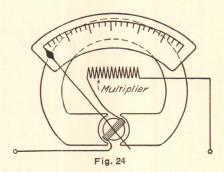
The small current flows through the springs and through the coil. You know what happens then—a magnetic field is set up about the armature coil. This field joins forces with the field

Fig. 22   Fig. 23

of the permanent magnet—the tendency being for the lines of force of each field to get into a straight line with each other. A force is exerted, which either pushes or pulls the armature, depending upon the direction of current flow, overcoming the pressure exerted in the opposite direction by the spiral springs to a degree depending on the current in the coil. The greater the current, the more lines of force about the armature and the nearer these lines of force will approach a parallel position in respect to the field of the permanent magnet. Of course, as the lines of force move, the armature moves along with them, causing the pointer attached to it, to move over the dial.

If larger currents are to be measured with a small current-carrying ammeter, several alloy strips of comparatively low resistance, placed between two copper lugs (the assembly is called a "shunt") are connected across the terminals of the ammeter as shown in Fig. 23. The shunt divides the current so

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that only a small part of the total current flows through the meter. The dial is then marked to read large values of current, although here again, only a small current is actually passing through the armature coil. Thus it is possible to measure amperes while using a milliammeter with a shunt. External shunts as in Fig. 23, can also be used.

An ammeter must be connected in series with the load. The same readings will result whether the ammeter is placed in the negative connecting wire or in the positive wire—it is a very interesting principle of electricity that the same amount of current flows through any point in a series circuit. The energy used to produce the movement of the needle, and consequently the deflection of the needle, is in proportion to the amount of current flowing through the circuit. Therefore, by first knowing how much current flows, the scale of Fig. 22 can be marked in

Fig. 24

amperes, or milliamperes, then when the same amount flows at some other time, the meter will tell us so by deflecting the needle to the same position.
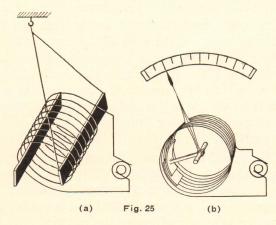
THE D. C. VOLTMETER

If we take any ammeter with a series resistance load and change the amount of *voltage* across the circuit, then the needle will deflect in proportion to the change in voltage. Reduce the voltage one-half, then the current through the meter will be one-half. Reduce the voltage still more and the meter needle will deflect less. The amount of voltage used each time can be marked on the scale and it is evident that such an arrangement will show when similar voltages are used again. The combined instrument of an ammeter and a comparatively large load in series, as shown in Fig. 24, is known as a voltmeter.

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Therefore a voltmeter consists of an ammeter (always a milliammeter) in series with a resistance. The resistance is used as a fixed load to send known currents through the armature as different voltages are applied. The fixed load is known as a multiplier and it is a permanent part of a voltmeter.

A voltmeter is connected across a source of e.m.f. (in parallel) to measure its voltage. Likewise when measuring any voltage, the voltmeter is connected in parallel to the points where the difference in potential is measured.

In measuring voltage it is desirable to use a current meter which will draw very little current. Consequently, the multiplier must be of high resistance.

A *galvanometer* which is used in experimental and laboratory work is nothing more than a very sensitive ammeter, de-

(a)   Fig. 25   (b)

signed to read in milliamperes or microamperes. The principles involved in its construction are the same as those of the voltmeter and ammeter.

By using resistances or shunts of known values, a galvanometer can be used as a very accurate voltmeter or ammeter.

A. C. METERS

Up to this point we have been speaking of meters used in measuring D.C. currents. Different types of meters must be used with A.C. current—if an ordinary galvanometer were put in an A.C. circuit, the needle would tend to swing back and forth with each reversal of current flow—and if the frequency of the current was anything but very low, the reversals would be too

rapid for the needle to follow and it would stand perfectly still at the zero line.

But alternating currents must be measured, and Weston adapted the D'Arsonval principle to A.C. use in a very simple and ingenious way. He made use of the principle that "like poles repel." See Fig. 25a.

The working elements of the A.C. meter are a coil and two iron plates inside the coil, one fastened to the coil, the other free to move. The pointer is attached to the free plate and when the pointer is at zero, the plates are together and in line—the free plate held in place by a fine spring, as in Fig. 25b.

When an A.C. current is passed through the coil, the iron plates are magnetized by the magnetic field about the coil. Both plates are magnetized alike. Because the north poles and south poles of these two plates, which are now magnets, are near each other, the free plate tends to move away from the fixed plate. When the current reverses, the ends of the plates which had been the north poles become the south poles and vice versa. But the repelling force is still there—the free plate will still be repelled by the fixed plate, and the greater the current, the greater will be the magnetism set up in the plates and the farther away the free plate will move, causing the needle to show a correspondingly larger reading.

A.C. meters read only about 70% of the maximum voltages —this being known as the *effective* voltage. Now you will ask, "How about the time when no current is flowing, twice during each cycle?" You will say that there is bound to be some change or flicker in the reading as the current rises and drops to zero. This is taken care of by a damping vane on the needle. It is a thin plate attached to the pointer needle, and moves in a closed air compartment. Thus, when the maximum repelling effect has taken place, the damping vane will tend to hold the pointer in position momentarily, just long enough so that the next half of the cycle will catch it before it has a chance to drop back toward zero.

Meters working on this principle are "repulsion" type meters. They can, by special construction, also be used to measure direct currents in which case the polarity of the plates does not change but the repelling effect is still present.

And now we come to the end of our fourth lesson. In this lesson, we have learned quite a great deal of the way an electric

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current acts in series and in parallel circuits and how the voltage and current are measured. In this lesson we have considered only the elementary circuits used in electrical work and Radio; more complete circuits will be studied in future lessons. Your knowledge of Radio is increasing quite rapidly, and with each lesson we dig deeper into the great storehouse of interesting information and knowledge the study of Radio opens up for us.

TEST QUESTIONS

Number your Answers 4FR and add your *Student Number*.

Never hold up one set of Lesson Answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What is an electrical circuit?

2. What are the essential parts of every electrical circuit?

3. What is meant by the load in a circuit?

4. State the difference between conductors, resistors and insulators?

5. What is the purpose of using insulating material on wires?

6. How may sources of e.m.f., conductors or loads be connected together?

7. What happens to electrical energy passing through conductors having resistance?

8. Why is copper wire usually used for the transmission wires in an electrical or Radio circuit?

9. How is an ammeter connected in a circuit?

10. How is a voltmeter connected in a circuit?