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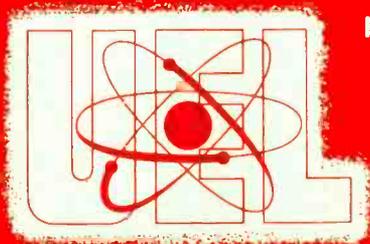
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OHM'S LAW — SERIES PARALLEL CIRCUITS

ASSIGNMENT 17B

OHM'S LAW—SERIES PARALLEL CIRCUITS

The importance of a thorough understanding of Ohm's Law and its application to electronics circuits cannot be overemphasized. Only when you have a thorough understanding of this subject may you progress to the operation of complete electronics circuits such as power supplies, amplifiers, oscillators, etc.

The subject of Ohm's Law, particularly as applied to series circuits and parallel circuits, has been discussed in two previous assignments—Assignment 6 and Assignment 8B. These two assignments should be reviewed very carefully before proceeding with the present assignment as the information presented in this assignment will be based on that of the aforementioned assignments.

Basic Circuit Arrangements

The three possible basic circuit arrangements have been discussed in detail in previous assignments and are illustrated in Figure 1 for the purpose of review. The three possible circuit arrangements are: The **series circuit**, **parallel circuit**, and the **series-parallel circuit**. The factor which determines whether a circuit constitutes a series, parallel, or series-parallel arrangement is the manner in which the current flows in the circuit. If there is only one path for the current from the negative terminal of the power source to the positive terminal, as illustrated in Figure 1(A), the circuit arrangement is a series circuit. If two or more paths are provided for the current, as illustrated in the circuit of Figure 1(B), the circuit arrangement is called a parallel circuit.

If a circuit contains one or more parallel networks which are in series with other components in the circuit, the arrangement is called a series-parallel circuit. Such an arrangement is shown in Figure 1(C). In this case it will be noted that the current path from the negative terminal of the voltage source is through resistor R_1 to the junction of resistors R_2 and R_3 . At this point the current divides, part of the current flowing through R_2 and the remaining portion of the current flowing through R_3 . Thus R_2 and R_3 are in parallel. However, the total current from the battery flows through the resistor R_1 and then through the parallel combination R_2 and R_3 . Thus the circuit arrangement of Figure 1(C) represents a combination of a series circuit and a parallel circuit and is commonly called a series-parallel circuit.

Since the subjects of series circuits and parallel circuits have been considered in detail in the previous assignments, no further discussion of these subjects should be required at the present time. Consequently this assignment will deal with the operation of the series-parallel circuits.

Series-Parallel Circuits

The explanation of series-parallel circuits requires the use of no new information. The knowledge which has been gained concerning series circuits and parallel circuits in the preceding assignments is merely applied to series-parallel circuits.

To illustrate the manner in which a series-parallel circuit may be handled, consider Figure 2(A). Let us first examine the circuit. When the current from the negative terminal of the battery reaches point A, it finds two paths to follow: therefore the 30 ohm and 70 ohm resistors are in parallel. After flowing through this parallel combination of the 30 ohm and 70 ohm resistors, the two branches of current again combine at point B. The total current then flows through the 3 ohm resistor back to the positive terminal of the battery.

There are a number of things which are known about the circuit of Figure 2(A) and there are a number of things which can be determined by applying to the circuit the knowledge previously gained concerning Ohm's Law. The known factors are the value of applied voltage and the ohmic value of resistors R_1 , R_2 and R_3 . The unknown factors in the circuit are: the current through R_1 , the current through R_2 , the current through R_3 , the voltage drop across resistors R_1 and R_2 , and the voltage drop across resistor R_3 .

Let us first outline just how the problem presented by this circuit should be solved, and then retrace our steps and solve it for the numerical values of current and voltage. As we have seen by tracing the current paths, the 30 ohm and the 70 ohm resistors are in parallel. The first step is to find the equivalent resistance of this parallel combination and redraw the circuit as shown in Figure 2(B), substituting this equivalent resistance for the two parallel resistors. Next we find the equivalent resistance of the two series resistors of the equivalent circuit of Figure 2(B). This gives us the second equivalent circuit as shown in Figure 2(C). From this circuit we can find the total current, and then we can find the voltage drops throughout the circuit.

The solution of a problem such as this is a step-by-step process. The calculations will be numbered: 1, 2, 3, etc. in the order in which they are made. Study the solution of this problem carefully but do not attempt to memorize the steps. After working a few problems yourself, you will find that a little thought, rather than memory work, will be sufficient.

(1). As mentioned previously the first step in the solution to the problem presented by the circuit in Figure 2(A) is to find the equivalent resistance of the 30 ohm and the 70 ohm parallel resistors. This can most conveniently be done by employing the **Product over Sum** formula.

$$R_e = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_e = \frac{30 \times 70}{30 + 70}$$

$$R_e = \frac{2100}{100}$$

$$R_e = 21 \Omega$$

This value of 21 ohms is placed in the first equivalent circuit of Figure 2(B).

(2). The next step in the solution, is to find the equivalent resistance of the two series resistors in the circuit of Figure 2(B). To find the equivalent resistance of the 21 ohm equivalent resistance and the 3 ohm resistor, we substitute these values in the series resistor formula.

$$R_t = R_e + R_3$$

$$R_t = 21 + 3$$

$$R_t = 24 \Omega$$

These calculations have provided us with the necessary information for the second equivalent circuit of Figure 2(C) and indicate that the total opposition offered to the flow of current in the circuit of Figure 2(A) is 24 ohms. After this information has been determined it is a simple matter to determine the total current in the circuit.

(3). The battery voltage in the circuit of Figure 2 is known to be 72 volts and the total opposition offered to the flow of current has been computed to be 24 ohms. With this information we can find the total current by applying Ohm's Law:

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

$$I = \frac{72}{24}$$

$$I = 3 \text{ amps}$$

By examining the circuit of Figure 2(B) it can be determined that the total current of 3 amperes flows through the equivalent resistance of 21 ohms and through the 3 ohm resistor. This information may be used to determine the voltage drops in the circuit.

(4). The voltage drop across the 3 ohm resistor may be determined by application of Ohm's Law since the value of current and the ohmic value of the resistance is known. It will be recalled that the voltage drop across

any resistor is equal to the current flowing through that resistor times the ohmic value of the resistance, or stated mathematically:

$$E = I \times R$$

$$E = 3 \times 3$$

$$E = 9 \text{ volts}$$

Thus there is a voltage drop of 9 volts across the 3 ohm resistor in the circuit of Figure 2(B) or, for that matter across the 3 ohm resistor in the circuit of Figure 2(A).

The **total current** flows through the **equivalent resistance** of R_1 and R_2 . Notice that only part of this current flows through R_1 and the rest of it flows through R_2 . If we were to attempt to find the voltage drop across either of these resistors by multiplying the total current times the ohmic value of one of the resistors, we would be in error. To find the voltage across the parallel combination of R_1 and R_2 , multiply the **total current** times the **equivalent resistance** of the combination.

(5). As determined by previous calculations and indicated in the equivalent circuit of Figure 2(B), the equivalent resistance of the parallel resistor combination is 21 ohms and the total current flowing in the circuit is 3 amperes. To find the voltage drop across the equivalent resistance, Ohm's Law formula is applied and the equivalent resistance is substituted in the formula.

$$E = I \times R_e$$

$$E = 3 \times 21$$

$$E = 63 \text{ volts}$$

The voltage drop across the equivalent resistance of 21 ohms in the circuit of Figure 2(B) is 63 volts. This is the voltage which would appear between points A and B in the circuit of Figure 2(A). Since resistors R_1 and R_2 are in parallel the same voltage is applied to each of them, and is in this case, 63 volts.

(6). It is now a simple matter to find the current flowing through the 70 ohm resistor and the 30 ohm resistor since we have determined the voltage across each to be 63 volts.

Current through 30 ohm resistor

Current through 70 ohm resistor

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

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

$$I = \frac{63}{30}$$

$$I = \frac{63}{70}$$

$$I = 2.1 \text{ amperes}$$

$$I = .9 \text{ ampere}$$

circuit of Figure 2(A) let us tabulate our results by filling in the following REI table.

REI table for circuit of Figure 2(A)

R	E	I
3	9	3
30	63	2.1
70	63	.9

A check of the answers to this type of problem can be made by adding up the voltage drops to see if they equal the applied voltage. In this case there is a 9 volt drop across R_3 and 63 volts across the parallel network. The total drop is $9 + 63 = 72$ volts which is equal to the applied voltage. Notice that we added the 63 volts only once since this **same** voltage is applied across both resistors R_1 and R_2 . Notice also that the sum of the currents flowing through R_1 and R_2 is equal to the total current which was found to be 3 amperes. ($2.1 \text{ amperes} + .9 \text{ ampere} = 3 \text{ amperes}$.)

After reading the foregoing discussion concerning the solution to the problem presented by the circuit of Figure 2(A) it may appear that such a solution is a difficult process. Quite the contrary is true, however, as it will be noted that all of the calculations involved are quite simple. The only complicated thing about the process is determining the proper order which should be used in the solution. This is determined by examining the circuit to determine the known values and the unknown values. The known values should then be used to determine the unknown values in a step-by-step process.

Another Example

Figure 3(A) illustrates another series-parallel circuit. This circuit is somewhat similar to the circuit of Figure 2(A) except one more resistor is present. Let us find the current flowing through each resistor and the voltage drop present across each resistor of the circuit.

The first step in the solution of the circuit that is illustrated in Figure 3 is, once again, to trace the current path in the circuit. In this particular case the current leaves the voltage source at the negative terminal and the entire current flows through resistor R_1 . Thus we know that this resistor forms a series component in the circuit. However, as the current progresses it reaches a junction of R_2 and R_3 at point A. Here the current divides, part flowing through R_2 and the remaining portion of the current flowing through R_3 . Thus we know that R_2 and R_3 are parallel resistors. The two branches of current again combine at point B and the entire current flows through resistor R_4 returning to the positive terminal of the voltage source. This indicates that R_4 is a series component. The next step is to draw the first equivalent circuit as shown in Figure 3(B). In

this case the circuit consists of a series arrangement composed of R_1 , the equivalent resistance of the parallel resistor network between points A and B, and R_4 . The next step in the solution of the problem is to find the total resistance represented by R_1 plus the equivalent resistance of R_2 and R_3 plus R_4 which produces the equivalent circuit illustrated in Figure 3(C). After this has been done it will be possible to determine the total current flowing in the circuit, the voltage drop across each resistor, and the current flowing through each resistor.

Let us now solve this problem numerically numbering each step as in the preceding example.

(1). As explained, the first step in the solution of the problem is to find the equivalent resistance of the two parallel resistors R_2 and R_3 . Since these resistors are of equal ohmic value it will be possible to apply the formula $R_e = \frac{R}{N}$ to determine the equivalent resistance.

$$R_e = \frac{R}{N}$$

$$R_e = \frac{50}{2}$$

$$R_e = 25 \Omega$$

Thus the equivalent resistance of resistors R_2 and R_3 is found to be 25 ohms and this value should be inserted in the equivalent circuit shown in Figure 3(B).

(2). The next step in the solution is to determine the total resistance represented by R_1 , the equivalent resistance of R_2 and R_3 , and R_4 . Since these are series components as represented in the equivalent circuit of Figure 3(B) the series resistor formula will be employed.

$$R_t = R_1 + R_e + R_4$$

$$R_t = 10 + 25 + 15$$

$$R_t = 50 \Omega$$

Thus the total resistance of the circuit is found to be 50 ohms. This value should be substituted in the equivalent circuit of Figure 3(C).

(3). Now that the total opposition to the current flow in the circuit has been determined, the amount of current flowing can be computed by the application of Ohm's Law.

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

$$I = \frac{25}{50}$$

$$I = .5 \text{ ampere}$$

The voltage drops in the circuit can now be determined since the current and resistance values are now known factors. Let us use the first equivalent circuit of Figure 3(B) to compute the voltage drops.

(4). The total current flows from the negative terminal of the battery through resistor R_1 . The amount of current is .5 ampere and the value of R_1 is 10 ohms. Ohm's Law is applied to determine the voltage across this resistor.

$$E = I \times R$$

$$E = .5 \times 10$$

$$E = 5 \text{ volts}$$

(5). The **total current** flows through the equivalent resistance present between points A and B in the circuit of Figure 3(B). The value of this equivalent resistance has been computed to be 25 ohms. Ohm's Law is applied to determine the voltage present between these two points.

$$E = I \times R$$

$$E = .5 \times 25$$

$$E = 12.5 \text{ volts}$$

(6). The voltage present across resistor R_4 can be determined in two ways. One manner of determining this voltage is to apply Ohm's Law since the values of resistance and current are known. The other method is to add together the voltage drop present across R_1 and the voltage drop present across the equivalent resistance between points A and B and subtract this value of voltage from the total supply voltage. These two methods will be demonstrated.

To determine the voltage drop present across R_4 by Ohm's Law the following calculations should be performed:

$$E = I \times R$$

$$E = .5 \times 15$$

$$E = 7.5 \text{ volts}$$

To find the voltage present across R_4 by the other method, the value of voltage across R_1 and the voltage across the equivalent resistance of R_2 and R_3 should be added together or in this case $5 + 12.5 = 17.5$. This value of voltage should be subtracted from the total supply voltage of 25 volts.

$$25 - 17.5 = 7.5 \text{ volts}$$

All of the factors concerning the circuit of Figure 3(A) have now been determined except the amount of current flowing through resistor R_2 and resistor R_3 . It has, of course, been determined that the voltage applied to each resistor is 12.5 volts, and the sum of the currents flowing through these two resistors is .5 ampere. We wish, however, to determine the amount of current which flows through each of the resistors at this time.

(7). In this particular circuit the amount of current which flows through R_2 and R_3 can be determined by inspection. Since these two resistors are

equal in value, it is obvious that they offer the same amount of opposition to the current flow. Consequently equal currents will flow through the two branches or, in other words, half of the total current flows through R_2 and the other half flows through R_3 . Since the total current is .5 ampere, the current through R_2 is .25 ampere and the current through R_3 is .25 ampere. If desired, however, the current through these two components can be determined by calculation. The voltage drop present between points A and B is 12.5 volts, and the ohmic value of R_2 and R_3 is 50 ohms each.

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

$$I = \frac{12.5}{50}$$

$$I = .25 \text{ ampere}$$

The foregoing calculations have provided all of the required information concerning the circuit of Figure 3(A). This information is tabulated in the following REI table.

REI table for circuit of Figure 3(A)

R	E	I
10	5	.5
50	12.5	.25
50	12.5	.25
15	7.5	.5

Still Another Example

Figure 4(A) represents a series-parallel circuit which should serve as an excellent example of the procedure used in solving the problems presented by series-parallel circuits.

As in the preceding circuits the first step which should be employed in the solution of the circuit of Figure 4(A) is to trace the current path. The current flow in this case is from the negative terminal of the 500 volt source, through R_1 , through R_2 to point A, which is the junction of three resistors. At this point the current divides. A portion flows through R_3 , another portion through R_4 , and the remaining portion through R_5 . The branch currents combine at point B and return to the positive terminal of the voltage source. Thus resistors R_3 , R_4 and R_5 are in parallel, and their equivalent resistance is in series with R_1 and R_2 . This is illustrated in the equivalent circuit of Figure 4(B). It should, by this time, be obvious to the Associate that the first step in the solution of this problem, will be to determine the equivalent resistance of the three parallel resistors, so

that the value of this equivalent resistance can be substituted in the circuit of Figure 4(B). After this has been done, it is then possible to determine the total resistance of the three resistors, producing the equivalent circuit shown in Figure 4(C). Then the voltage drops throughout the circuit and the current through the three individual parallel resistors can be determined.

(1). The equivalent resistance of the three parallel resistors can be determined either by the application of the reciprocal formula, or by applying the Product over Sum formula, to determine the equivalent resistance of two of these units, and then reapplying the formula using this equivalent resistance and the third value of resistance. We will illustrate the use of the reciprocal formula.

$$\frac{1}{R_e} = \frac{1}{100 \times 10^3} + \frac{1}{200 \times 10^3} + \frac{1}{200 \times 10^3}$$

$$\frac{1}{R_e} = \frac{2 + 1 + 1}{200 \times 10^3} = \frac{4}{200 \times 10^3}$$

$$R_e = \frac{200 \times 10^3}{4}$$

(Note: Lowest common denominator is 200×10^3)

$$R_e = 50 \times 10^3 \text{ or } 50\text{k } \Omega$$

(2). Now that the equivalent resistance of the three parallel resistors has been determined, this value should be inserted in the equivalent circuit of Figure 4(B) and the total opposition of the three resistors of this equivalent circuit should be determined by application of the series resistor formula as follows:

$$R_t = R_1 + R_2 + R_e$$

$$R_t = 300 \times 10^3 + 150 \times 10^3 + 50 \times 10^3$$

$$R_t = 500 \times 10^3 \text{ or } 500\text{k } \Omega$$

This value should be substituted for the equivalent resistance shown in the circuit of Figure 4(C).

(3). To find the total current flowing in the circuit of Figure 4(A) it is only necessary to apply Ohm's Law using the total voltage indicated and the total resistance as computed in the circuit of Figure 4(C). This is done as follows:

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

$$I = \frac{500}{500 \times 10^3}$$

$$I = \frac{500 \times 10^{-3}}{500}$$

$$I = 1 \times 10^{-3} \text{ or } .001 \text{ ampere or } 1 \text{ mA}$$

The foregoing calculations indicate that 1 milliampere of current flows in the circuit, and as illustrated by the circuit of Figure 4(B) passes through R_1 , R_2 , and the equivalent resistance (R_e) of R_3 , R_4 and R_5 . With this information it is possible to compute the voltage drops across these components.

(4). To find the voltage across resistor R_1 it is only necessary to apply Ohm's Law using the value of resistance indicated in the figure and the computed value of current.

$$E = I \times R$$

$$E = .001 \times 300,000$$

$$E = 300 \text{ volts}$$

(5). The voltage drop across resistor R_2 is computed in a similar manner.

$$E = I \times R$$

$$E = .001 \times 150,000$$

$$E = 150 \text{ volts}$$

(6). The voltage present across the parallel combination can be determined by two methods as mentioned in the previous example. Let us illustrate the method of calculating this voltage drop. This is a relatively simple process as the total current flowing is known and the equivalent resistance has been determined to be 50,000 ohms. Thus to find the voltage drop present from point A to B, Ohm's Law will be applied using the current value of .001 ampere and the equivalent resistance of 50,000 ohms.

$$E = I \times R$$

$$E = .001 \times 50,000$$

$$E = 50 \text{ volts}$$

(7). The voltage present between points A and B, which has been computed to be 50 volts, is applied across resistors R_3 , R_4 and R_5 . Thus Ohm's Law can be applied to determine the current flowing through each.

Current through R_3

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

$$I = \frac{50}{100,000}$$

$$I = .0005 \text{ ampere or } .5 \text{ mA}$$

Current through R_4

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

$$I = \frac{50}{200,000}$$

$$I = .00025 \text{ ampere or } .25 \text{ mA}$$

Current through R_5

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

$$I = \frac{50}{200,000}$$

$$I = .00025 \text{ ampere or } .25 \text{ mA}$$

This completes the calculations for the problem presented by the circuit of Figure 4(A). The following REI table is a tabulation of the values found.

REI table for the circuit of Figure 4.

R	E	I
300 k	300	1 mA
150 k	150	1 mA
100 k	50	.5 mA
200 k	50	.25 mA
200 k	50	.25 mA

Solve This Example

The circuit of Figure 5(A) represents a more complex series-parallel circuit. When the current paths of the circuit of Figure 5(A) are traced, it will be found that resistors R_2 and R_3 are in parallel and also that resistors R_4 , R_5 and R_6 are in parallel. When the equivalent resistances of these two parallel networks are substituted for the networks the equivalent circuit represented in Figure 5(B) is produced which can, in turn, be reduced to the equivalent circuit of Figure 5(C).

To determine the voltage drops throughout the circuit of Figure 5(A) and the current flowing in the individual resistors, a technique similar to that employed in the previous circuits will be used.

(1). As may be determined by examining Figure 5(B) the first step in the solution is to find the equivalent resistance of R_2 and R_3 which form a parallel arrangement. The equivalent resistance of these two resistors can be found most conveniently by employing the Product over Sum formula.

$$R_e = \frac{R_2 \times R_3}{R_2 + R_3}$$

$$R_e = \frac{9000 \times 1000}{9000 + 1000}$$

$$R_e = \frac{9,000,000}{10,000}$$

$$R_e = 900 \Omega$$

(2). The equivalent resistance of the three 6,000 ohm resistors can be determined by applying the formula $R_e = \frac{R}{N}$.

$$R_e = \frac{6000}{3}$$

$$R_e = 2000 \Omega$$

The values of equivalent resistance found for the two parallel networks should be inserted in the equivalent circuit of Figure 5(B).

(3). The total opposition offered to the current flow in the circuit can now be computed by applying the series resistor formula.

$$\begin{aligned} R_t &= R_1 + R_e + R_e + R_7 \\ R_t &= 2,100 + 900 + 2,000 + 3,000 \\ R_t &= 8,000 \Omega \end{aligned}$$

This value of total resistance should be inserted in the equivalent circuit of Figure 5(C).

(4). Now that the total resistance in the circuit has been determined, the total current can be computed very easily by the application of Ohm's Law.

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

$$I = \frac{240}{8,000}$$

$$I = .03 \text{ ampere or } 30 \text{ mA}$$

This entire current of 30 milliamperes flows through each resistor or **equivalent resistance** shown in the circuit of Figure 5(B). After this information has been determined we can determine the voltage drops across the individual resistors, or equivalent resistances.

Voltage across R_1

$$\begin{aligned} E &= IR \\ E &= .03 \times 2100 \\ E &= 63 \text{ volts} \end{aligned}$$

Voltage across R_e of R_4 , R_5 and R_6
(between points C and D)

$$\begin{aligned} E &= IR \\ E &= .03 \times 2000 \\ E &= 60 \text{ volts} \end{aligned}$$

Voltage across R_2 and R_3
(between points A and B)

$$\begin{aligned} E &= IR \\ E &= .03 \times 900 \\ E &= 27 \text{ volts} \end{aligned}$$

Voltage across R_7

$$\begin{aligned} E &= IR \\ E &= .03 \times 3000 \\ E &= 90 \text{ volts} \end{aligned}$$

(5). The current through the individual resistors in the parallel network can now be determined. Since the voltage present from point A to point B is 27 volts, the voltage present across the resistors R_2 and R_3 is 27 volts. To find the current through each resistor, Ohm's Law is applied.

To find current through R_2

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

$$I = \frac{27}{9000}$$

$$I = .003 \text{ ampere or } 3 \text{ mA}$$

To find current through R_3

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

$$I = \frac{27}{1000}$$

$$I = .027 \text{ ampere or } 27 \text{ mA}$$

(6). The current flowing through R_4 , R_5 and R_6 can be determined by computation or inspection. It will be noted that these resistors are of equal value, thus they offer equal opposition to the flow of current. In other words the current flow from point C to point D is evenly divided between three resistors. Thus 10 milliamperes of current flows through R_4 , 10 milliamperes through R_5 and 10 milliamperes through R_6 .

These calculations have provided all the necessary information regarding the circuit of Figure 5(A). For convenience they are tabulated below in the REI table.

REI table for circuit of Figure 5(A).

R	E	I
2.1k	63	.03
9k	27	.003
1k	27	.027
6k	60	.01
6k	60	.01
6k	60	.01
3k	90	.03

Voltage Drops

As explained in a previous assignment the polarity of voltage drops in a circuit can be determined very simply. It is only necessary to remember that as the current flows through the circuit, the end of a resistor which the current enters is negative with respect to the other end of that resistor. To illustrate the application of this principle to a series-parallel circuit, Figure 6 shows the current paths and the polarity of the voltage drops in the circuit of Figure 5(A). Notice that as the current enters resistor R_1 at point X and leaves at point A, the polarity of the voltage drop across this resistor is such that point X is negative with respect to point A. Notice also that the current enters the parallel combination formed by resistors R_2 and R_3 at point A, and leaves at point B making this voltage drop of such polarity that point A is negative with respect to point B. Similarly the current enters the parallel network formed by resistors R_4 , R_5 and R_6 at point C, and leaves at point D, making the voltage drop between these two points negative at point C, and positive at point D. The current flow through R_7 enters at the end of the resistor labeled E, and leaves at the end labeled F, making the voltage drop between these two points negative at point E and positive at point F. Now insert in Figure 6 the various values of voltage indicated in the REI table for the circuit of Figure 5(A). Add up the various voltage drops and see if you agree

with the statement made in a previous assignment, that the sum of the voltage drops around the circuit is equal to the applied voltage. Remember that there is **only one voltage drop** present across a **parallel combination**. That is, there is only one voltage drop from point A to B, and this same voltage is applied to the two resistors connected between these points. Thus in adding the voltage drops around the circuit, the voltage drop across each of the parallel networks should be added only once.

Later on in vacuum tube work we will be interested in the voltage between different points along a circuit. We speak of these voltages as the **Difference of Potential** between points. Once the voltage drops in a circuit have been determined, it takes but a moment to determine any and all differences of potential. Be sure that you have inserted the value of the various voltage drops in the circuit of Figure 6 before proceeding with the following discussion.

Since there is a 63 volt drop across resistor R_1 , and point X is negative with respect to point A, we can say that point X is 63 volts negative with respect to point A, or we can say, if we choose, that point A is 63 volts positive with respect to point X. In a similar manner we can state that point B is 27 volts positive with respect to point A, or that point A is 27 volts negative with respect to point B. If we wish to determine the difference of potential between point X and point B this can be done by merely adding up the voltage drops between these two points. Thus point X is 90 volts negative with respect to point B ($63 + 27$).

Similarly, point C is 60 volts negative with respect to point D, or in other words point D is 60 volts positive with respect to point C.

Similarly, point E is 90 volts negative with respect to point F, or in other words point F is 90 volts positive with respect to point E.

Similarly, point C is 150 volts negative with respect to point F, or in other words point F is 150 volts positive with respect to point C.

Analyze Figure 6 carefully and determine for yourself the difference in potential between points E and A, between points F and A, between points X and D, and between points X and F.

When speaking of differences in potential in a circuit there are two terms which are often employed. In some cases it will be stated that a certain point is "so many volts **above** another point." Another expression which is used is that one point is "so many volts **below** another point." The term **above** means "positive with respect to," and the term **below** means "negative with respect to." This arrangement is employed as it is simpler to say that point X in the circuit of Figure 6 is 63 volts below point A than it is to say that point X is 63 volts negative with respect to point A. Similarly we can say that point A is 63 volts above point X, that point B is 90 volts above point X, and that point C is 60 volts below point D.

To further illustrate the manner in which the difference in potential in a circuit can be considered, examine the circuit of Figure 7 which is a vacuum tube circuit. Connected across the battery are three resistors in

series. The polarity and value of the voltage drop across each resistor are shown in the figure. The control grid, labeled (G) in the figure, is 10 volts negative with respect to the cathode. The screen grid, labeled (SG) in the illustration, is 200 volts positive with respect to the cathode, or we could say that the screen grid is 200 volts above the cathode. What is the plate voltage with respect to the cathode? In a vacuum tube amplifier circuit the voltage of the various elements in the tube with respect to the cathode is a very important factor. For this reason the importance of understanding the term difference of potential should be obvious.

A Different Kind of Problem

Figure 8 represents a series-parallel circuit somewhat similar to those which have been discussed previously. However, in this case it is desired to determine a different factor than in the circuits considered previously. The known factors in the circuit of Figure 8 are the battery voltage of 18 volts, the voltage drop across the parallel resistor network and the total current flowing in the circuit. The factor which is to be determined is the ohmic value of the resistor R.

It will be recalled that any time current flow occurs through a resistor a voltage drop will be produced across that resistor. In the circuit of Figure 8, if 1.2 amperes of current flow from the negative terminal of the battery and through the four parallel resistors it must also flow through the resistor labeled R. This will produce a voltage drop across this resistor with the polarity as indicated in the diagram. Since a voltage drop of only 12.6 volts occurs across the parallel resistor combination, the voltage which appears across resistor R must be equal to 18 volts minus 12.6 volts. The value of the voltage drop across resistor R is therefore 5.4 volts. Since it has been determined that a voltage of 5.4 volts is present across resistor R and the current through this resistor is 1.2 amperes, the manner in which the ohmic value of resistor R can be determined should present itself to you. It is only necessary to apply Ohm's Law as follows:

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

$$R = \frac{5.4}{1.2}$$

$$R = 4.5 \Omega$$

Figure 9 illustrates a practical electronics circuit in which a series-parallel arrangement is employed to secure the desired results. Let us assume that four vacuum tubes which have filaments of 21 ohm resistance each are to be operated from an 8 volt battery. Let us assume further that the manufacturer of the tubes recommends that .3 ampere of current be supplied to each. The filaments of the tubes can be connected in

parallel as shown in Figure 9 and a resistor R of the correct ohmic value inserted between the tubes and the battery so that the voltage applied to the tubes will be the correct value.

Let us first determine the amount of voltage which should be applied to the parallel network consisting of the four filaments. The ohmic value of each of the filaments is 21 ohms and .3 ampere of current should be passed through each. We can determine the voltage which should be applied to the filaments through the application of Ohm's Law.

$$E = IR$$

$$E = .3 \times 21$$

$$E = 6.3 \text{ volts}$$

Since the filaments are connected in parallel the 6.3 volts should be applied to the parallel combination. However, the battery voltage is 8 volts as indicated in the figure. Therefore, we will have to place a resistor in series with the parallel branch so that a voltage drop will occur across the resistor and leave only 6.3 volts across the parallel filaments. If only 6.3 volts are to be applied to the filaments the voltage drop which occurs across the resistor R must be 1.7 volts. (8 volts — 6.3 volts = 1.7 volts.)

Now that we have determined the voltage drop which must be present across resistor R let us determine the current which will flow through this resistor. Since each of the filaments passes .3 ampere of current the total current flowing in the circuit will be 1.2 amperes and this value of current will pass through resistor R. We now have obtained the necessary information for determining the ohmic value of resistor R since we know the voltage drop present across the resistor and the current flowing through the resistor.

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

$$R = \frac{1.7}{1.2}$$

$$R = 1.42 \Omega$$

The problem as represented by Figures 7 and 9 have been included to illustrate the fact to you that Ohm's Law will serve a very practical purpose in your electronics work. This subject is not merely a theoretical discussion which will be of little benefit. Instead Ohm's Law will be applied repeatedly in the continued work on electronics circuits to such an extent that you will find that the task of solving circuit problems becomes simple.

A Slightly Different Circuit

Figure 10 represents a series-parallel circuit which is slightly different from those which have been encountered previously. This can be noted by tracing the current path in the circuit. From the negative ter-

minal of the voltage source the current first passes through resistor R_1 and arrives at point A, the junction of resistors R_2 and R_4 . At this point the current divides and a portion of the current flows through resistor R_4 . The remaining portion of the current flows through resistor R_2 . However, this current also flows through resistor R_3 before recombining with the current passing through resistor R_4 at the junction point B. The combined current then returns to the positive terminal of the voltage source.

If the current paths in the circuit of Figure 10 are analyzed carefully it should be apparent that resistors R_2 and R_3 are in series since the same current flows through each of them. Further analysis should reveal the fact that this series combination of R_2 and R_3 is in parallel with resistor R_4 . The parallel network between points A and B is in turn in series with R_1 . In solving the problem presented by this circuit the method which should be employed is as follows: First the equivalent resistance of R_2 and R_3 should be found. Then the equivalent resistance of the resistor R_4 and the two series resistors R_2 and R_3 should be found. After this has been done the total opposition of the circuit should be determined, after which the individual voltage drops throughout the circuit can be computed.

(1). Since resistors R_2 and R_3 are in series, the series resistor formula should be used to find their equivalent resistance.

$$R_t = R_2 + R_3$$

$$R_t = 2,000 + 4,000$$

$$R_t = 6,000 \Omega$$

(2). The equivalent resistance of R_2 and R_3 should be substituted in the circuit of Figure 10(B), and the parallel network solved to find its equivalent resistance. Since the two branches of the parallel circuit of Figure 10(B) are equal in value the following formula may be used.

$$R_e = \frac{R}{N}$$

$$R_e = \frac{6,000}{2}$$

$$R_e = 3,000 \Omega$$

(3). The equivalent resistance of 3,000 ohms for the parallel network should be substituted in the circuit of Figure 10(C) and the total resistance computed. Since this equivalent resistance is in series with R_1 the series resistor formula is employed.

$$R_t = R_1 + R_e$$

$$R_t = 1,000 + 3,000$$

$$R_t = 4,000 \Omega$$

This value of resistance should then be placed in the circuit of Figure 10(D).

(4). Now that the total opposition offered to the current flow in the

circuit has been computed the current flowing in the circuit can be determined by Ohm's Law.

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

$$I = \frac{80}{4,000}$$

$$I = .02 \text{ ampere or } 20 \text{ mA}$$

(5). Since the total current has been determined the voltage drop present across R_1 can be computed by Ohm's Law.

$$E = IR$$

$$E = .02 \times 1,000$$

$$E = 20 \text{ volts}$$

(6). The equivalent resistance of the parallel network has been computed to be 3,000 ohms. Ohm's Law can be used to determine the voltage across this network.

$$E = IR$$

$$E = .02 \times 3,000$$

$$E = 60 \text{ volts}$$

(7). The current through the individual branches of the parallel network can be determined in this particular case by inspection since the two branches of the parallel network are equal in resistance. This will cause the current to divide evenly and 10 milliamperes of current will flow through each branch. It would be possible to compute this current by Ohm's Law since the applied voltage is known and the resistance of each branch is known. For example if it were desired to compute the current flowing through the branch consisting of R_2 and R_3 the circuit of Figure 10(B) should be examined to determine the fact that the total resistance of this branch is 6,000 ohms. As determined in the previous step the voltage across the parallel network is 60 volts and Ohm's Law can be applied to determine the current flow through the branch of the circuit consisting of R_2 and R_3 . This is done as follows:

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

$$I = \frac{60}{6,000}$$

$$I = .01 \text{ ampere or } 10 \text{ mA}$$

(8). 10 milliamperes of current flows through R_2 and R_3 . To determine the voltage drop across each of these resistors Ohm's Law is applied.

To find the voltage drop across R_2 To find the voltage drop across R_3

$$E = IR$$

$$E = .01 \times 2,000$$

$$E = 20 \text{ volts}$$

$$E = IR$$

$$E = .01 \times 4,000$$

$$E = 40 \text{ volts}$$

The foregoing has completed the solution of the problem presented by the circuit of Figure 10. This information is tabulated in the following REI table.

REI table for the circuit of Figure 10

R	E	I
1 k	20	20 mA
2 k	20	10 mA
4 k	40	10 mA
6 k	60	10 mA

Practice

Figures 11, 12, 13 and 14 illustrate series circuits, parallel circuits and series-parallel circuits. For review in the solution of series and parallel circuits and practice in the solution of problems presented by series-parallel circuits, you are advised to solve the problems presented by these circuits and fill in the REI tables. In addition the current paths should be indicated by means of dotted arrows and the polarity of each voltage drop should be shown. After these calculations have been performed check your answers against those shown at the end of this assignment.

Summary

This assignment has illustrated the manner in which the problems presented by series-parallel circuits should be solved. These circuits cannot be solved in one operation. To solve the problems presented by such a circuit a logical procedure must be followed as outlined in the assignment. This method sometimes requires a rather long process, but the mathematical calculations involved are usually simple. The understanding of the manner in which various factors concerning these circuits can be determined will be very important to you as you progress in the training, as series-parallel circuits are often encountered in electronics circuits.

"HOW TO PRONOUNCE . . ."

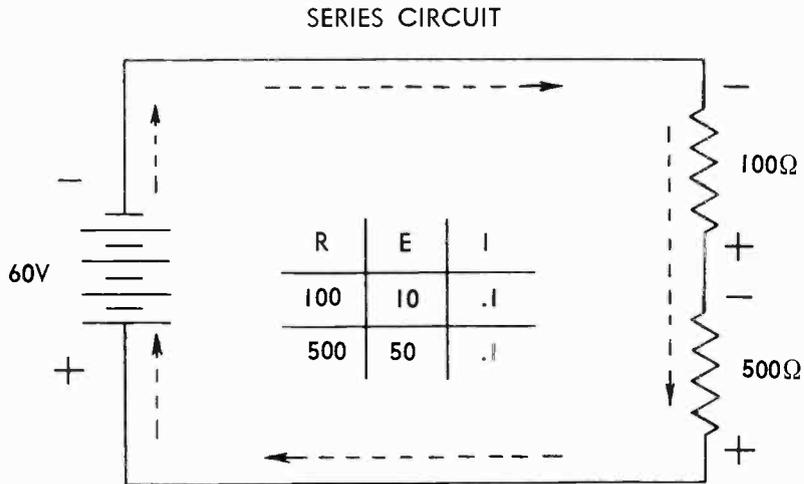
(Note: the accent falls on the part shown in CAPITAL letters.)

compute	(konn-PEWT)
computation	(KOMM-pew-TAYE-shun)
ohmic	(OWE-mikk)
reciprocal	(reh-SIPP-raw-KULL)

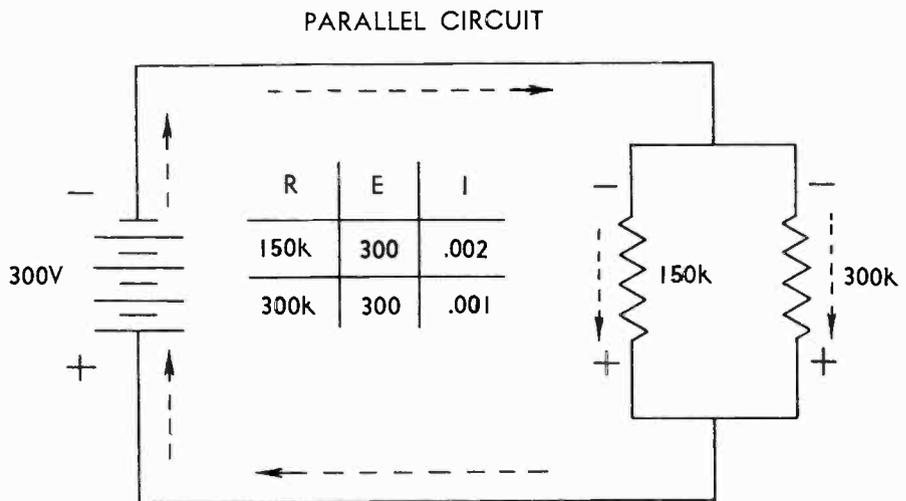
Answers to Exercise Problems

Problems 11, 12, 13 and 14.

11.

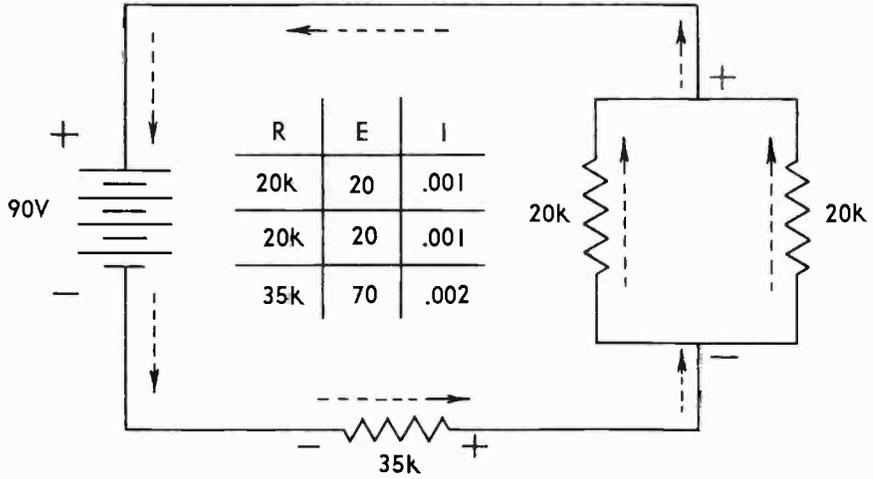


12.



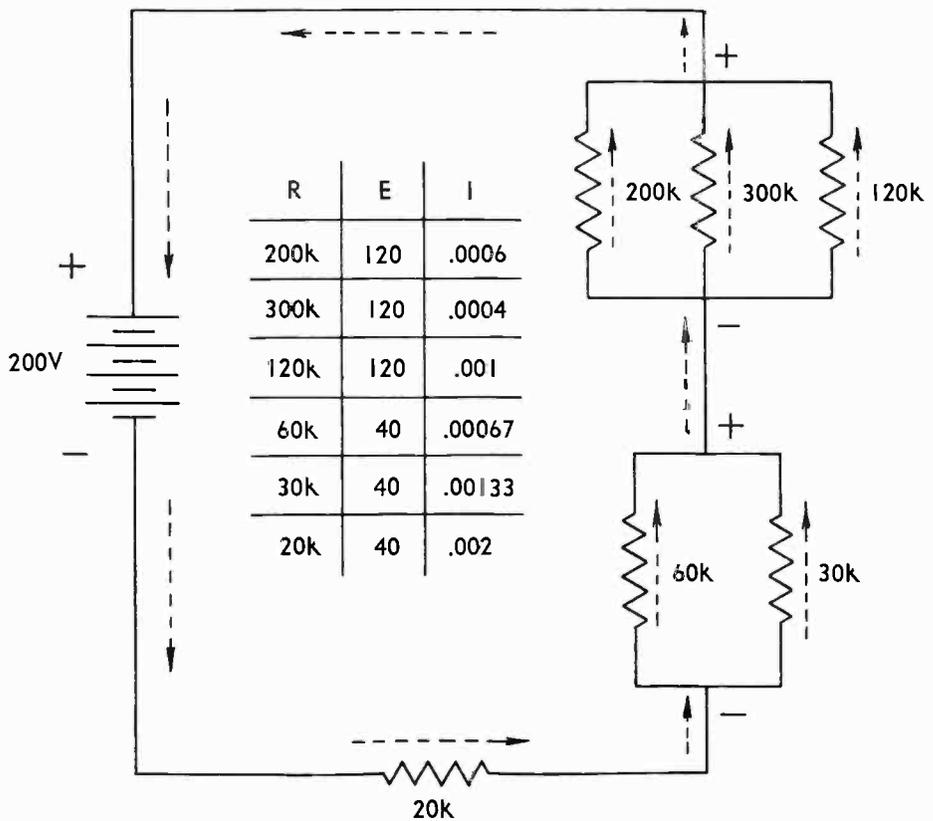
SERIES-PARALLEL CIRCUIT

13.



SERIES-PARALLEL CIRCUIT

14.



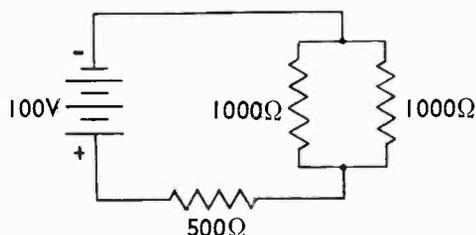
Test Questions

Be sure to number your Answer Sheet Assignment 17B

Place your Name and Associate Number on **every** Answer Sheet.

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

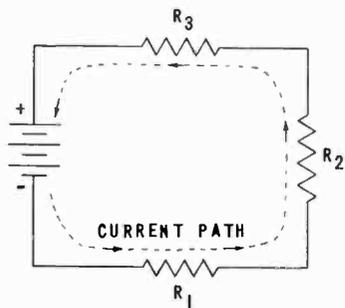
1. Draw a **schematic** diagram of a series circuit consisting of a 20 volt battery, a 1,000, a 2,000, and a 3,000 ohm resistor. Indicate the direction of current flow by means of a dotted arrow and indicate the polarity of each voltage drop in the circuit.
2. Draw a schematic diagram of a parallel circuit consisting of a 10 volt battery, a 2,000 ohm resistor, a 4,000 ohm resistor, and a 6,000 ohm resistor. Indicate by means of dotted arrows the current paths in the circuit, and also indicate the polarity of the voltage drops.
3. In the circuit of Figure 6, what is the difference of potential of point F with respect to point A?
4. Show three (3) forms of Ohm's Law.
5. State in your own words how it is possible to determine the polarity of the voltage drop across a resistor if the direction of the current flow through that resistor is known.
6. In the accompanying diagram what is the equivalent resistance of the two parallel resistors?



7. In the circuit of Question 6 what would be the total opposition to the flow of current in the circuit?
8. In the circuit of Question 6 what value of current would flow through the 500 ohm resistor?
9. In the circuit of Question 6 what would be the value of the voltage drop across the 500 ohm resistor?
10. In the circuit of Question 6 what would be the value of the voltage drop present across the parallel resistor network?
(To check your answers to Question 9 and 10 recall the fact that the sum of the voltage drops must equal the source voltage.)

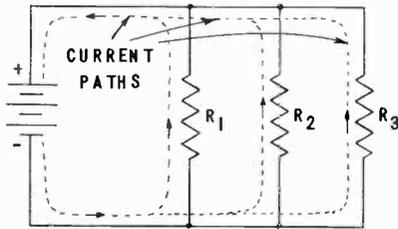
BASIC CIRCUITS

SERIES CIRCUIT



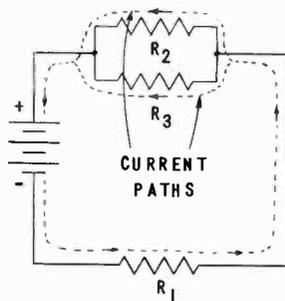
(A)

PARALLEL CIRCUIT



(B)

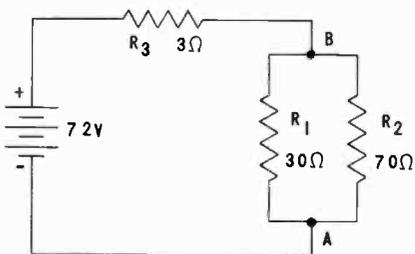
SERIES-PARALLEL CIRCUIT



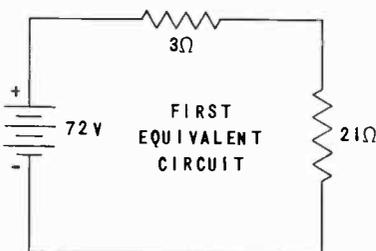
(C)

FIGURE 1

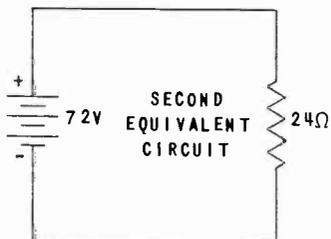
SERIES-PARALLEL CIRCUIT SOLUTION



(A)



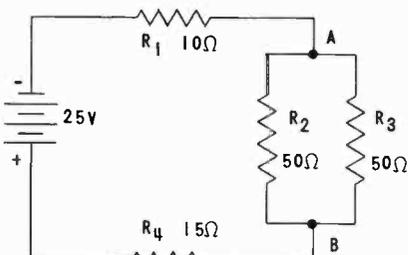
(B)



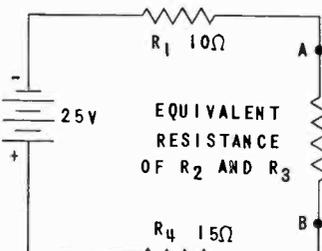
(C)

FIGURE 2

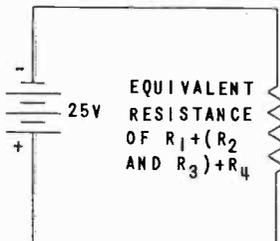
SERIES-PARALLEL CIRCUIT SOLUTION



(A)



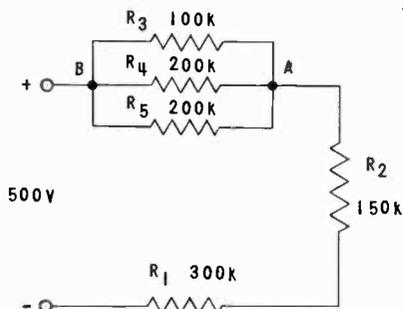
(B)



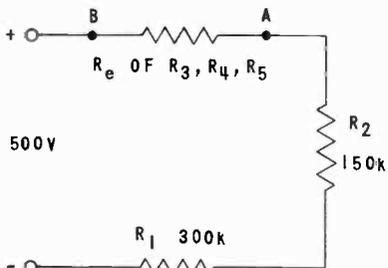
(C)

FIGURE 3

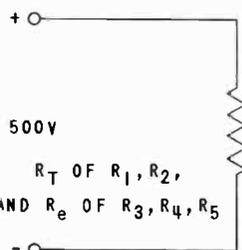
SERIES-PARALLEL CIRCUIT SOLUTION



(A)



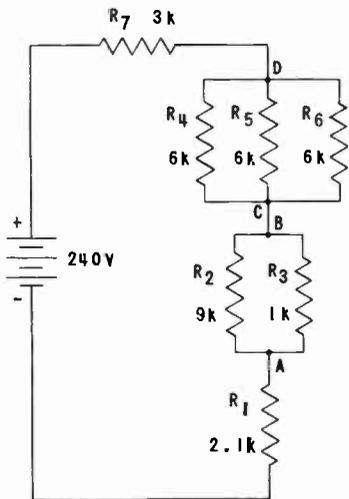
(B)



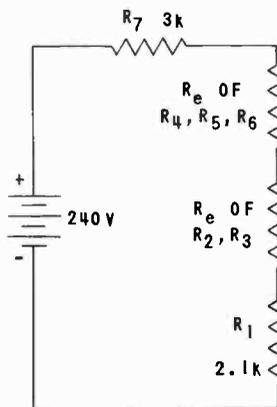
(C)

FIGURE 4

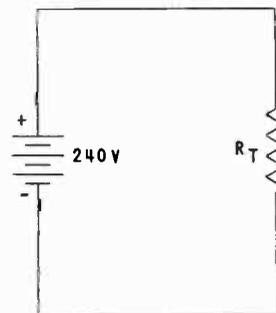
SERIES-PARALLEL CIRCUIT SOLUTION



(A)



(B)



(C)

FIGURE 5

CURRENT PATHS AND POLARITY OF VOLTAGE DROPS IN CIRCUIT OF FIGURE 5(A)

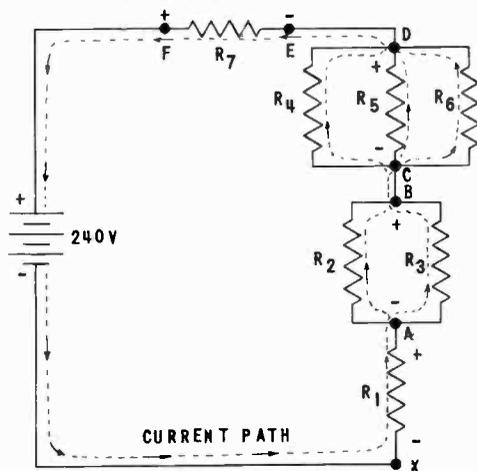


FIGURE 6

VACUUM TUBE CIRCUIT

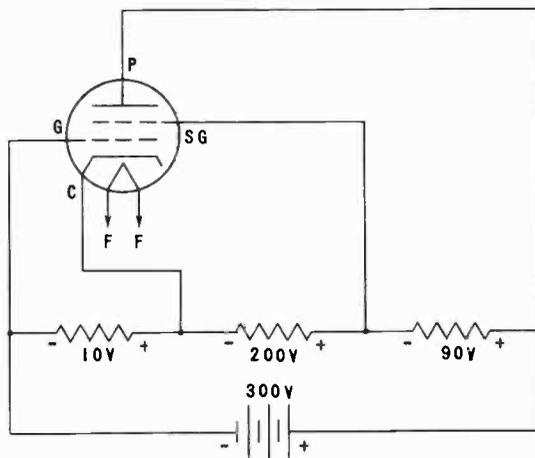


FIGURE 7

SERIES-PARALLEL CIRCUIT

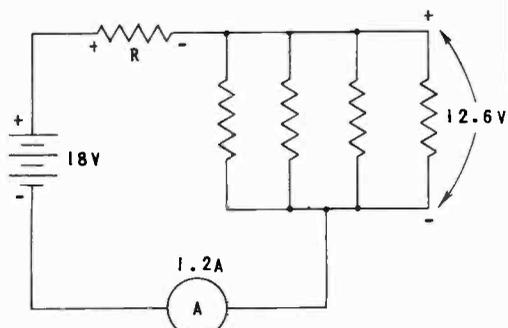


FIGURE 8

PRACTICAL RADIO CIRCUIT

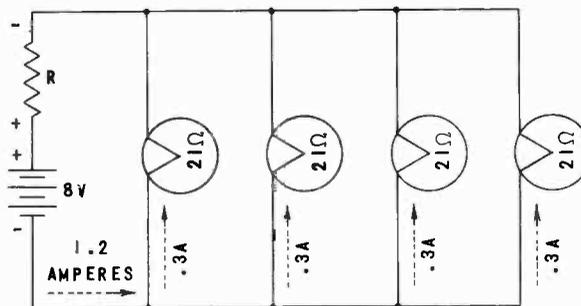


FIGURE 9

SERIES-PARALLEL CIRCUIT

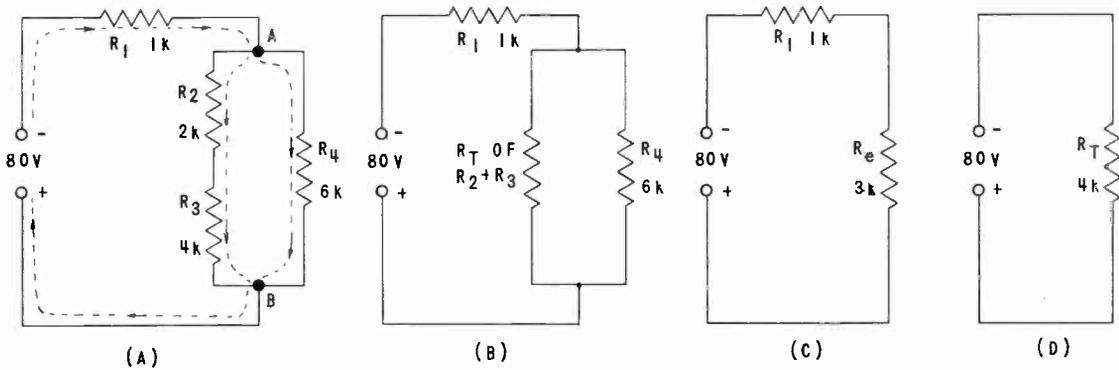


FIGURE 10

SERIES CIRCUIT

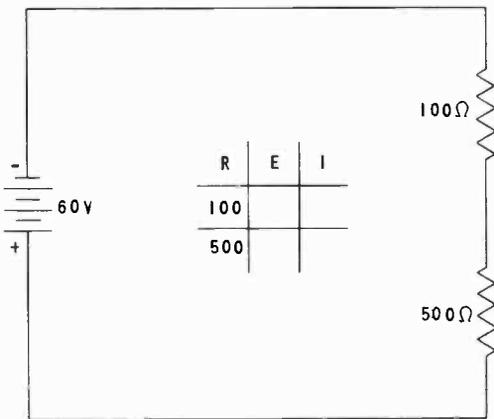


FIGURE 11

PARALLEL CIRCUIT

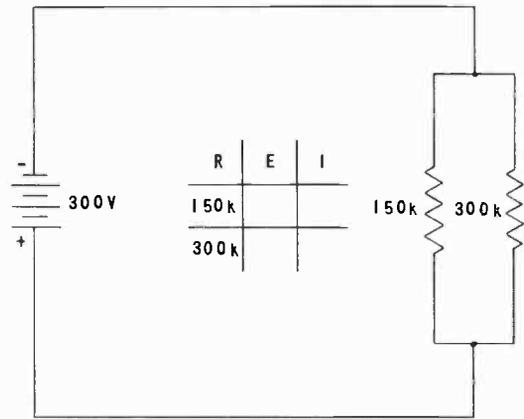


FIGURE 12

SERIES-PARALLEL CIRCUIT

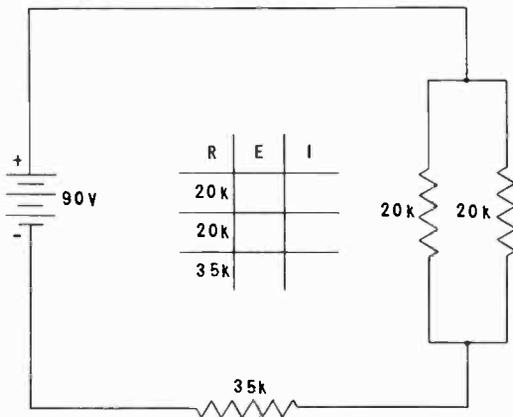


FIGURE 13

SERIES-PARALLEL CIRCUIT

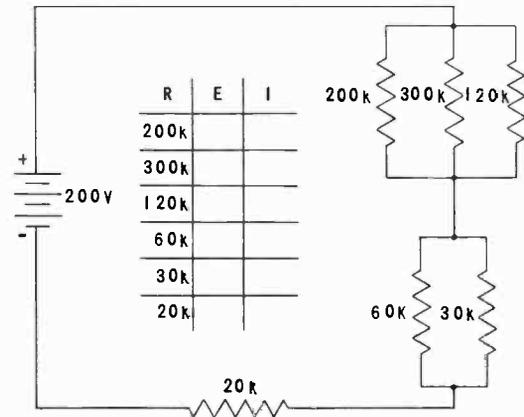


FIGURE 14