PDHonline Course E235 (4 PDH)

Electrical Fundamentals – Introduction to Direct Current (DC) Theory

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CHAPTER 3

DIRECT CURRENT

LEARNING OBJECTIVES

Upon completing this chapter, you will be able to:

1. Identify the term schematic diagram and identify the components in a circuit from a simple schematic diagram.
2. State the equation for Ohm's law and describe the effects on current caused by changes in a circuit.
3. Given simple graphs of current versus power and voltage versus power, determine the value of circuit power for a given current and voltage.
4. Identify the term power, and state three formulas for computing power.
5. Compute circuit and component power in series, parallel, and combination circuits.
6. Compute the efficiency of an electrical device.
7. Solve for unknown quantities of resistance, current, and voltage in a series circuit.
8. Describe how voltage polarities are assigned to the voltage drops across resistors when Kirchhoff's voltage law is used.
9. State the voltage at the reference point in a circuit.
10. Define open and short circuits and describe their effects on a circuit.
11. State the meaning of the term source resistance and describe its effect on a circuit.
12. Describe in terms of circuit values the circuit condition needed for maximum power transfer.
13. Compute efficiency of power transfer in a circuit.
14. Solve for unknown quantities of resistance, current, and voltage in a parallel circuit.
15. State the significance of the polarity assigned to a current when using Kirchhoff's current law.
16. State the meaning of the term equivalent resistance.
17. Compute resistance, current, voltage, and power in voltage dividers.
18. Describe the method by which a single voltage divider can provide both positive and negative voltages.
19. Recognize the safety precautions associated with the hazard of electrical shock.
20. Identify the first aid procedures for a victim of electrical shock.

INTRODUCTION

The material covered in this chapter contains many new terms that are explained as you progress through the material. The basic dc circuit is the easiest to understand, so the chapter begins with the basic circuit and from there works into the basic schematic diagram of that circuit. The schematic diagram is used in all your future work in electricity and electronics. It is very important that you become familiar with the symbols that are used.

This chapter also explains how to determine the total resistance, current, voltage, and power in a series, parallel, or combination circuit through the use of Ohm's and Kirchhoff's laws. The voltage divider network, series, parallel, and series-parallel practice problem circuits will be used for practical examples of what you have learned.

THE BASIC ELECTRIC CIRCUIT

The flashlight is an example of a basic electric circuit. It contains a source of electrical energy (the dry cells in the flashlight), a load (the bulb) which changes the electrical energy into a more useful form of energy (light), and a switch to control the energy delivered to the load.

Before you study a schematic representation of the flashlight, it is necessary to define certain terms. The LOAD is any device through which an electrical current flows and which changes this electrical energy into a more useful form. Some common examples of loads are a lightbulb, which changes electrical energy to light energy; an electric motor, which changes electrical energy into mechanical energy; and the speaker in a radio, which changes electrical energy into sound. The SOURCE is the device which furnishes the electrical energy used by the load. It may consist of a simple dry cell (as in a flashlight), a storage battery (as in an automobile), or a power supply (such as a battery charger). The SWITCH, which permits control of the electrical device, interrupts the current delivered to the load.

SCHEMATIC REPRESENTATION

The technician's main aid in troubleshooting a circuit in a piece of equipment is the SCHEMATIC DIAGRAM. The schematic diagram is a "picture" of the circuit that uses symbols to represent the various circuit components; physically large or complex circuits can be shown on a relatively small diagram. Before studying the basic schematic, look at figure 3-1. This figure shows the symbols that are used in this chapter. These, and others like them, are referred to and used throughout the study of electricity and electronics.

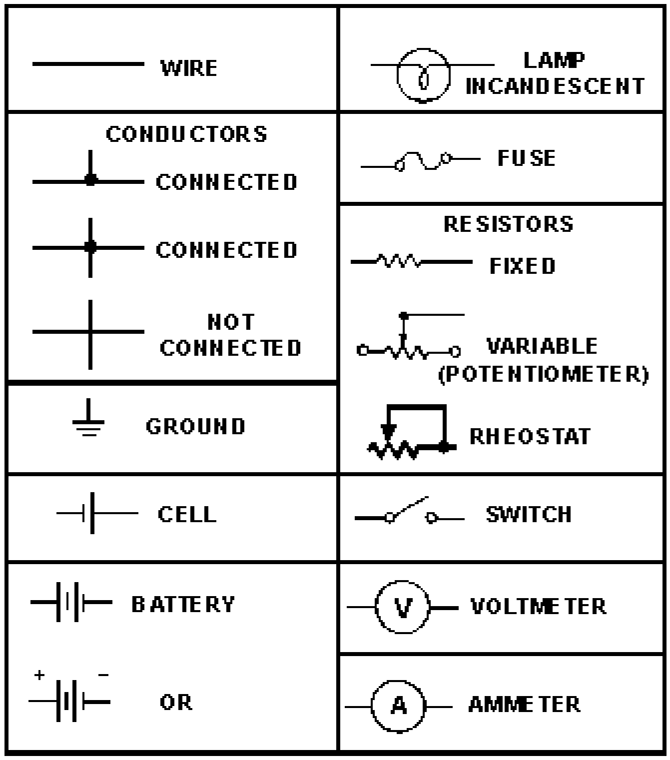


Figure 3-1.—Symbols commonly used in electricity.

The schematic in figure 3-2 represents a flashlight. View A of the figure shows the flashlight in the off or deenergized state. The switch (S1) is open. There is no complete path for current (I) through the circuit, and the bulb (DS1) does not light. In figure 3-2 view B, switch S1 is closed. Current flows in the direction of the arrows from the negative terminal of the battery (BAT), through the switch (S1), through the lamp (DS1), and back to the positive terminal of the battery. With the switch closed the path for current is complete. Current will continue to flow until the switch (S1) is moved to the open position or the battery is completely discharged.

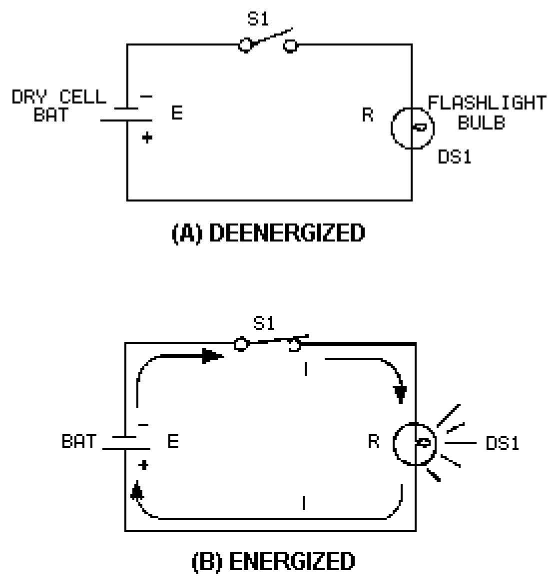


Figure 3-2.—Basic flashlight schematic.

Q1. In figure 3-2, what part of the circuit is the (a) load and (b) source?

Q2. What happens to the path for current when S1 is open as shown in figure 3-2(A)?

Q3. What is the name given to the "picture" of a circuit such as the one shown in figure 3-2?

OHM'S LAW

In the early part of the 19th century, George Simon Ohm proved by experiment that a precise relationship exists between current, voltage, and resistance. This relationship is called Ohm's law and is stated as follows:

The current in a circuit is DIRECTLY proportional to the applied voltage and INVERSELY proportional to the circuit resistance. Ohm's law may be expressed as an equation:

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

Where: I = current in amperes
E = voltage in volts
R = resistance in ohms

As stated in Ohm's law, current is inversely proportional to resistance. This means, as the resistance in a circuit increases, the current decreases proportionately.

In the equation

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

if any two quantities are known, the third one can be determined. Refer to figure 3-2(B), the schematic of the flashlight. If the battery (BAT) supplies a voltage of 1.5 volts and the lamp (DS1) has a resistance of 5 ohms, then the current in the circuit can be determined. Using this equation and substituting values:

$$I = \frac{E}{R} = \frac{1.5 \text{ volts}}{5 \text{ ohms}} = .3 \text{ ampere}$$

If the flashlight were a two-cell flashlight, we would have twice the voltage, or 3.0 volts, applied to the circuit. Using this voltage in the equation:

$$I = \frac{E}{R} = \frac{3.0 \text{ volts}}{5 \text{ ohms}} = .6 \text{ ampere}$$

You can see that the current has doubled as the voltage has doubled. This demonstrates that the <u>current is directly proportional to the applied voltage.</u>

If the value of resistance of the lamp is doubled, the equation will be:

$$I = \frac{E}{R} = \frac{3.0 \text{ volts}}{10 \text{ ohms}} = .3 \text{ ampere}$$

The current has been reduced to one half of the value of the previous equation, or .3 ampere. This demonstrates that the <u>current is inversely proportional to the resistance</u>. Doubling the value of the resistance of the load reduces circuit current value to one half of its former value.

APPLICATION OF OHM'S LAW

By using Ohm's law, you are able to find the resistance of a circuit, knowing only the <u>voltage</u> and the <u>current</u> in the circuit.

In any equation, if all the variables (parameters) are known except one, that unknown can be found. For example, using Ohm's law, if current (I) and voltage (E) are known, resistance (R) the only parameter not known, can be determined:

1. Basic formula:

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

2. Remove the divisor by multiplying both sides by R:

$$R \times I = \frac{E}{\cancel{R}} \times \frac{\cancel{R}}{1}$$

3. Result of step 2: R x I = E

4. To get R alone (on one side of the equation) divide both sides by I:

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

5. The basic formula, transposed for R, is:

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

Refer to figure 3-3 where E equals 10 volts and I equals 1 ampere. Solve for R, using the equation just explained.

Given: E = 10 volts

I = 1 ampere

Solution:

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

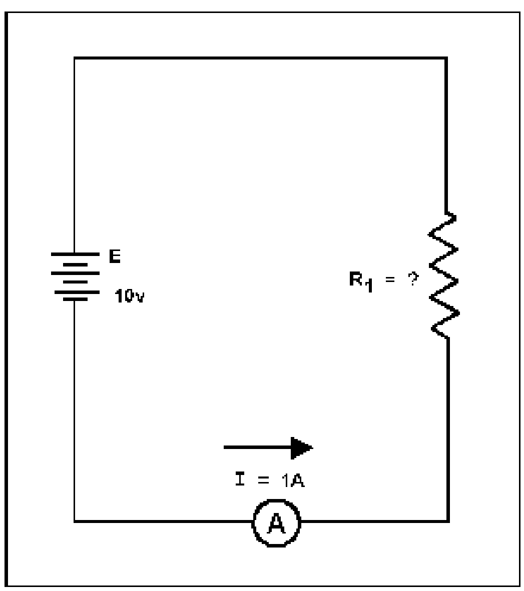


Figure 3-3.—Determining resistance in a basic circuit.

Insert the values of the known quantities:

$$R = \frac{10 \text{ volts}}{1 \text{ ampere}}$$

$$R = 10 \text{ ohms}$$

The basic formula can also be used to solve for E:

Take the basic formula: $I = \frac{E}{R}$

multiply both sides by R:

$$I \times R = \frac{E}{R} \times \frac{R}{1}$$

Results: $E = I \times R$

This equation can be used to find the voltage for the circuit shown in figure 3-4.

Given: $I = .5$ ampere
$R = 45$ ohms

Solution: $E = I \times R$
$E = .5 \text{ ampere} \times 45 \text{ ohms}$
$E = 22.5 \text{ volts}$

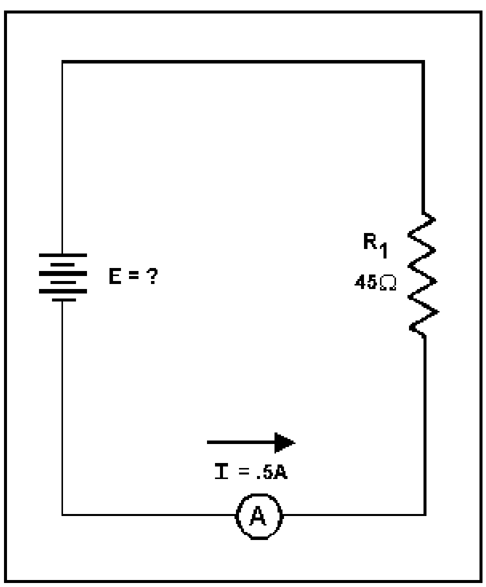


Figure 3-4.—Determining voltage in a basic circuit.

The Ohm's law equation and its various forms may be obtained readily with the aid of figure 3-5. The circle containing E, I, and R is divided into two parts, with E above the line and with I and R below the line. To determine the unknown quantity, first cover that quantity with a finger. The position of the uncovered letters in the circle will indicate the mathematical operation to be performed. For example, to find I, cover I with a finger. The uncovered letters indicate that E is to be divided by R, or

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

To find the formula for E, cover E with your finger. The result indicates that I is to be multiplied by R, or E = IR. To find the formula for R, cover R. The result indicates that E is to be divided by I, or

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

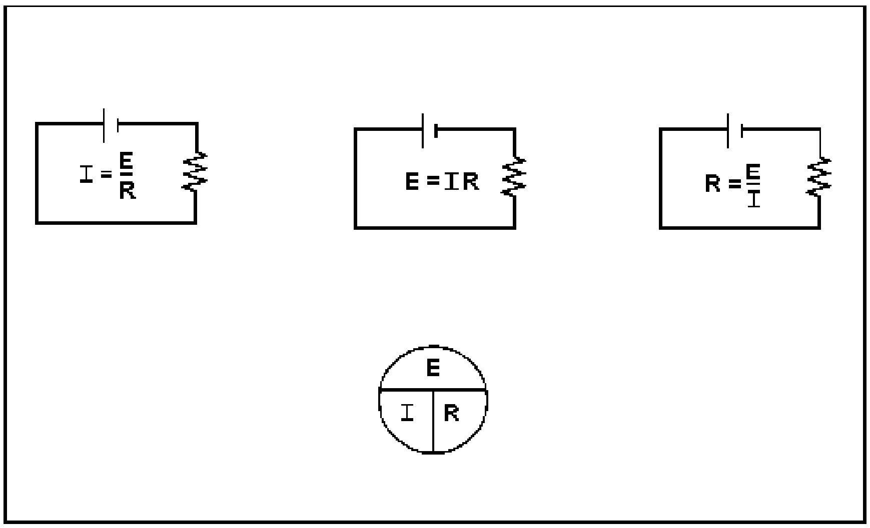


Figure 3-5.—Ohm's law in diagram form.

You are cautioned not to rely wholly on the use of this diagram when you transpose the Ohm's law formulas. The diagram should be used to supplement your knowledge of the algebraic method. Algebra is a basic tool in the solution of electrical problems.

Q4. According to Ohm's law, what happens to circuit current if the applied voltage (a) increases, (b) decreases?

Q5. According to Ohm's law, what happens to circuit current if circuit resistance (a) increases, (b) decreases?

Q6. What is the equation used to find circuit resistance if voltage and current values are known?

GRAPHICAL ANALYSIS OF THE BASIC CIRCUIT

One of the most valuable methods of analyzing a circuit is by constructing a graph. No other method provides a more convenient or more rapid way to observe the characteristics of an electrical device.

The first step in constructing a graph is to obtain a table of data. The information in the table can be obtained by taking measurements on the circuit under examination, or can be obtained theoretically through a series of Ohm's law computations. The latter method is used here.

Since there are three variables (E, I, and R) to be analyzed, there are three distinct graphs that may be constructed.

To construct any graph of electrical quantities, it is standard practice to vary one quantity in a specified way and note the changes which occur in a second quantity. The quantity which is intentionally varied is called the independent variable and is plotted on the horizontal axis. The horizontal axis is known as the X-AXIS. The second quantity, which varies as a result of changes in the first quantity, is called the dependent variable and is plotted on the vertical, or Y-AXIS. Any other quantities involved are held constant.

For example, in the circuit shown in figure 3-6, if the resistance was held at 10 ohms and the voltage was varied, the resulting changes in current could then be graphed. The resistance is the constant, the voltage is the independent variable, and the current is the dependent variable.

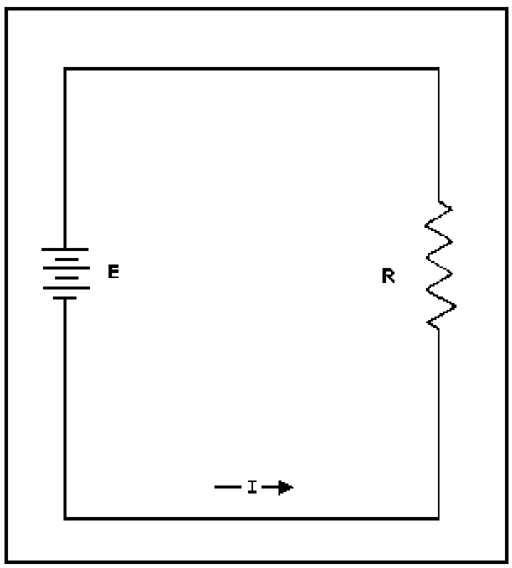
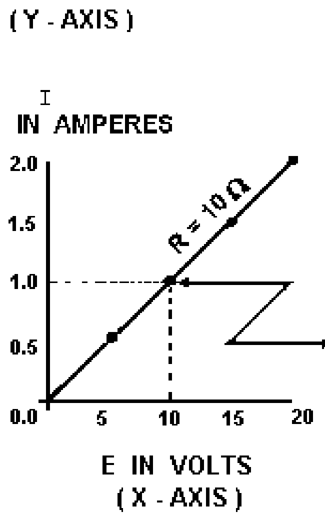


Figure 3-6.—Three variables in a basic circuit.

Figure 3-7 shows the graph and a table of values. This table shows R held constant at 10 ohms as E is varied from 0 to 20 volts in 5-volt steps. Through the use of Ohm's law, you can calculate the value of current for each value of voltage shown in the table. When the table is complete, the information it contains can be used to construct the graph shown in figure 3-7. For example, when the voltage applied to the 10-ohm resistor is 10 volts, the current is 1 ampere. These values of current and voltage determine a point on the graph. When all five points have been plotted, a smooth curve is drawn through the points.



R = 10 Ω	
E	I
0	0.0
5	0.5
10	1.0
15	1.5
20	2.0

Figure 3-7.—Volt-ampere characteristic.

Through the use of this curve, the value of current through the resistor can be quickly determined for any value of voltage between 0 and 20 volts.

Since the curve is a straight line, it shows that equal changes of voltage across the resistor produce equal changes in current through the resistor. This fact illustrates an important characteristic of the basic law—the current varies directly with the applied voltage when the resistance is held constant.

When the voltage across a load is held constant, the current depends solely upon the resistance of the load. For example, figure 3-8 shows a graph with the voltage held constant at 12 volts. The independent variable is the resistance which is varied from 2 ohms to 12 ohms. The current is the dependent variable. Values for current can be calculated as:

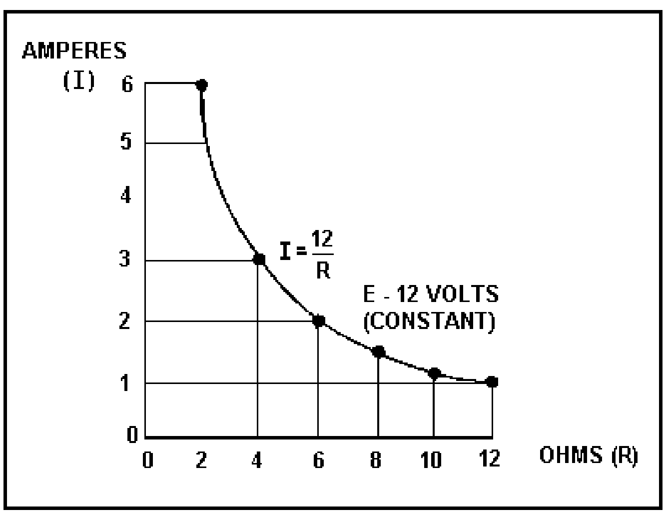


Figure 3-8.—Relationship between current and resistance.

Given: $E = 12 \text{ volts}$

$R = 2 \text{ ohms to } 12 \text{ ohms}$

Soultion: $I = \dfrac{E}{R}$

$$I = \frac{12 \text{ volts}}{12 \text{ ohms}} = 1 \text{ ampere}$$

$$I = \frac{12 \text{ volts}}{10 \text{ ohms}} = 12 \text{ ampere}$$

$$I = \frac{12 \text{ volts}}{8 \text{ ohms}} = 15 \text{ ampere}$$

$$I = \frac{12 \text{ volts}}{6 \text{ ohms}} = 2 \text{ ampere}$$

This process can be continued for any value of resistance. You can see that as the resistance is halved, the current is doubled; when the resistance is doubled, the current is halved.

This illustrates another important characteristic of Ohm's law—current varies inversely with resistance when the applied voltage is held constant.

Q7. Using the graph in figure 3-7, what is the approximate value of current when the voltage is 12.5 volts?

Q8. Using the graph in figure 3-8, what is the approximate value of current when the resistance is 3 ohms?

POWER

Power, whether electrical or mechanical, pertains to the rate at which work is being done. Work is done whenever a force causes motion. When a mechanical force is used to lift or move a weight, work is done. However, force exerted WITHOUT causing motion, such as the force of a compressed spring acting between two fixed objects, does not constitute work.

Previously, it was shown that voltage is an electrical force, and that voltage forces current to flow in a closed circuit. However, when voltage exists but current does not flow because the circuit is open, no work is done. This is similar to the spring under tension that produced no motion. When voltage causes electrons to move, work is done. The instantaneous RATE at which this work is done is called the electric power rate, and is measured in WATTS.

A total amount of work may be done in different lengths of time. For example, a given number of electrons may be moved from one point to another in 1 second or in 1 hour, depending on the RATE at which they are moved. In both cases, total work done is the same. However, when the work is done in a short time, the wattage, or INSTANTANEOUS POWER RATE, is greater than when the same amount of work is done over a longer period of time.

As stated, the basic unit of power is the watt. Power in watts is equal to the voltage across a circuit multiplied by current through the circuit. This represents the rate at any given instant at which work is being done. The symbol P indicates electrical power. Thus, the basic power formula is P = E x I, where E is voltage and I is current in the circuit. The amount of power changes when either voltage or current, or both voltage and current, are caused to change.

In practice, the ONLY factors that can be changed are voltage and resistance. In explaining the different forms that formulas may take, current is sometimes presented as a quantity that is changed. Remember, if current is changed, it is because either voltage or resistance has been changed.

Figure 3-9 shows a basic circuit using a source of power that can be varied from 0 to 8 volts and a graph that indicates the relationship between voltage and power.

The resistance of this circuit is 2 ohms; this value does not change. Voltage (E) is increased (by increasing the voltage source), in steps of 1 volt, from 0 volts to 8 volts. By applying Ohm's law, the current (I) is determined for each step of voltage. For instance, when E is 1 volt, the current is:

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

$$I = \frac{1 \text{ volt}}{2 \text{ ohms}}$$

$$I = 0.5 \text{ ampere}$$

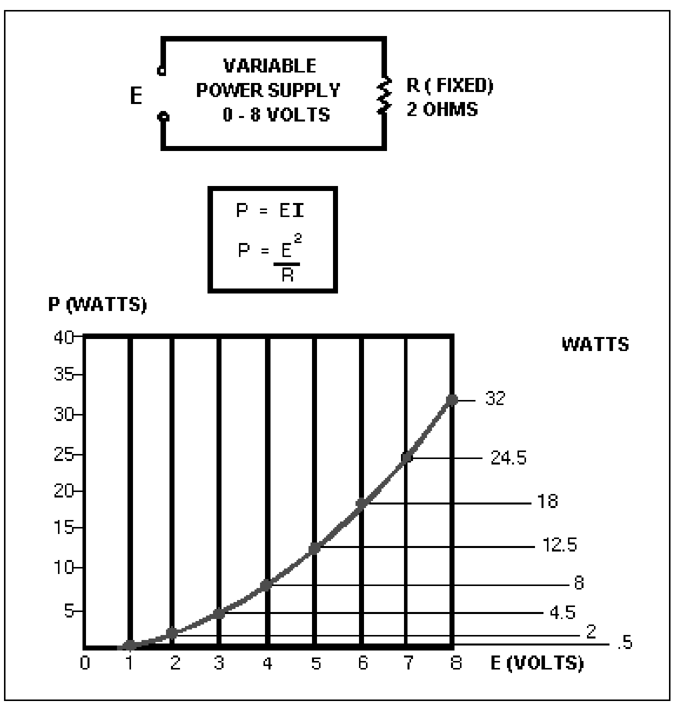


Figure 3-9.—Graph of power related to changing voltage.

Power (P), in watts, is determined by applying the basic power formula:

$$P = E \times I$$
$$P = 1 \text{ volt} \times 0.5 \text{ ampere}$$
$$P = 0.5 \text{ watt}$$

When E is increased to 2 volts:

$$I = \frac{E}{R}$$
$$I = \frac{2 \text{ volts}}{2 \text{ ohms}}$$
$$I = 1 \text{ ampere}$$

and

$$P = E \times I$$

$$P = 2 \text{ volts} \times 1 \text{ ampere}$$

$$P = 2 \text{ watts}$$

When E is increased to 3 volts:

$$I = \frac{E}{R}$$
$$I = \frac{3 \text{ volts}}{2 \text{ ohms}}$$
$$I = 1.5 \text{ amperes}$$

and

$$P = E \times I$$
$$P = 3 \text{ volts} \times 1.5 \text{ ampere}$$
$$P = 4.5 \text{ watts}$$

You should notice that when the voltage was increased to 2 volts, the power increased from .5 watts to 2 watts or 4 times. When the voltage increased to 3 volts, the power increased to 4.5 watts or 9 times. This shows that if the resistance in a circuit is held constant, the power varies directly with the SQUARE OF THE VOLTAGE.

Another way of proving that power varies as the square of the voltage when resistance is held constant is:

Since:	$I = \frac{E}{R}$
By substitution in:	$P = E \times I$
You get:	$P = E \times \frac{E}{R}$
Or:	$P = \frac{E \times E}{R}$
Therefore:	$P = \frac{E^2}{R}$

Another important relationship may be seen by studying figure 3-10. Thus far, power has been calculated with voltage and current (P = E x I), and with voltage and resistance

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

Referring to figure 3-10, note that power also varies as the square of current just as it does with voltage. Thus, another formula for power, with current and resistance as its factors, is $P = I^2R$. This can be proved by:

Since:	$E = I \times R$
By substituition in:	$P = E \times I$
You get:	$P = I \times R \times I$
Or:	$P = I \times I \times R$
Therefore:	$P = I^2 \times R$

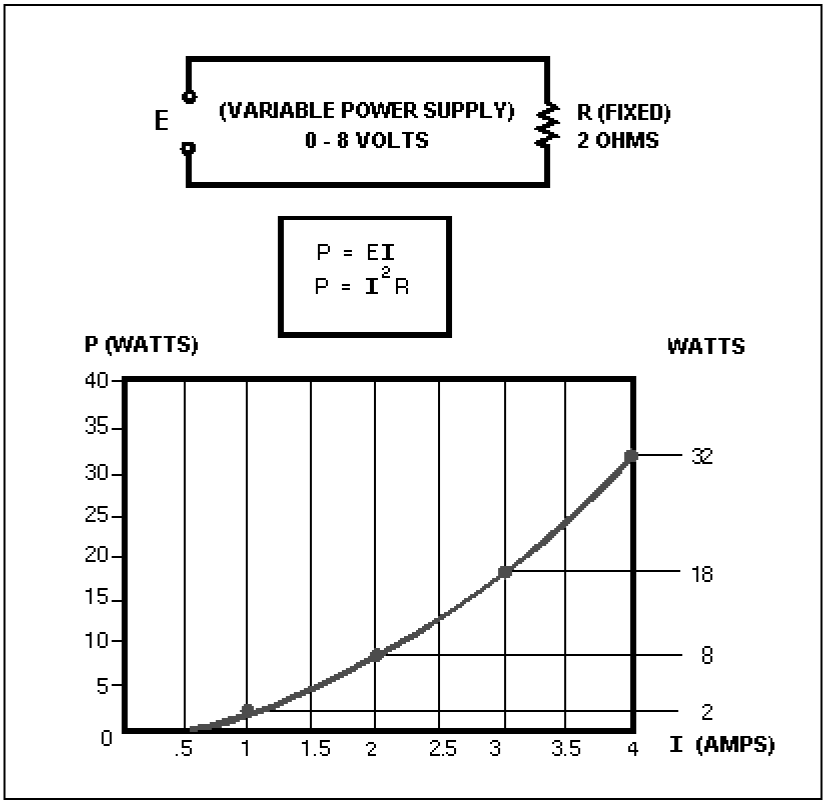


Figure 3-10.—Graph of power related to changing current.

Up to this point, four of the most important electrical quantities have been discussed. These are voltage (E), current (I), resistance (R), and power (P). You must understand the relationships which exist among these quantities because they are used throughout your study of electricity. In the preceding paragraphs, P was expressed in terms of alternate pairs of the other three basic quantities E, I, and R. In practice, you should be able to express any one of these quantities in terms of any two of the others.

Figure 3-11 is a summary of 12 basic formulas you should know. The four quantities E, I, R, and P are at the center of the figure. Adjacent to each quantity are three segments. Note that in each segment, the basic quantity is expressed in terms of two other basic quantities, and no two segments are alike.

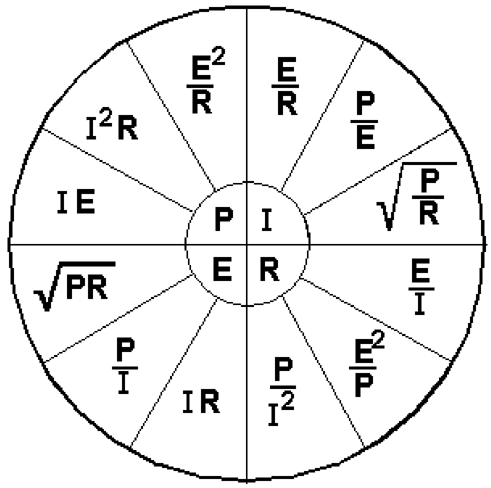


Figure 3-11.—Summary of basic formulas.

For example, the formula wheel in figure 3-11 could be used to find the formula to solve the following problem:

A circuit has a voltage source that delivers 6 volts and the circuit uses 3 watts of power. What is the resistance of the load?

Since R is the quantity you have been asked to find, look in the section of the wheel that has R in the center. The segment

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

contains the quantities you have been given. The formula you would use is

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

The problem can now be solved.

$$\text{Given:} \quad E = 6 \text{ volts}$$
$$P = 3 \text{ watts}$$

$$\text{Soultion:} \quad R = \frac{E^2}{P}$$
$$\frac{(6 \text{ volts})^2}{3 \text{ watts}}$$

$$R = \frac{36}{3} = 12 \text{ ohms}$$

Q9. What is the term applied to the rate at which a mechanical or electrical force causes motion?

Q10. How can the amount of current be changed in a circuit?

Q11. What are the three formulas for electrical power?

POWER RATING

Electrical components are often given a power rating. The power rating, in watts, indicates the rate at which the device converts electrical energy into another form of energy, such as light, heat, or motion. An example of such a rating is noted when comparing a 150-watt lamp to a 100-watt lamp. The higher wattage rating of the 150-watt lamp indicates it is capable of converting more electrical energy into light energy than the lamp of the lower rating. Other common examples of devices with power ratings are soldering irons and small electric motors.

In some electrical devices the wattage rating indicates the maximum power the device is designed to use rather than the normal operating power. A 150-watt lamp, for example, uses 150 watts <u>when operated at the specified voltage printed on the bulb</u>. In contrast, a device such as a resistor is not normally given a voltage or a current rating. A resistor is given a power rating in watts and can be operated at <u>any combination of voltage and current</u> as long as the power rating is not exceeded. In most circuits, the actual power used by a resistor is considerably less than the power rating of the resistor because a 50% safety factor is used. For example, if a resistor normally used 2 watts of power, a resistor with a power rating of 3 watts would be used.

Resistors of the same resistance value are available in different wattage values. Carbon resistors, for example, are commonly made in wattage ratings of 1/8, 1/4, 1/2, 1, and 2 watts. The larger the physical size of a carbon resistor the higher the wattage rating. This is true because a larger surface area of material radiates a greater amount of heat more easily.

When resistors with wattage ratings greater than 5 watts are needed, wirewound resistors are used. Wirewound resistors are made in values between 5 and 200 watts. Special types of wirewound resistors are used for power in excess of 200 watts.

As with other electrical quantities, prefixes may be attached to the word watt when expressing very large or very small amounts of power. Some of the more common of these are the kilowatt (1,000 watts), the megawatt (1,000,000 watts), and the milliwatt (1/1,000 of a watt).

Q12. What is the current in a circuit with 5 ohms of resistance that uses 180 watts of power? (refer to figure 3-12)

Q13. What type of resistor should be used in the circuit described in question 12?

Q14. What is the power used in a circuit that has 10 amperes of current through a 10-ohm resistor?

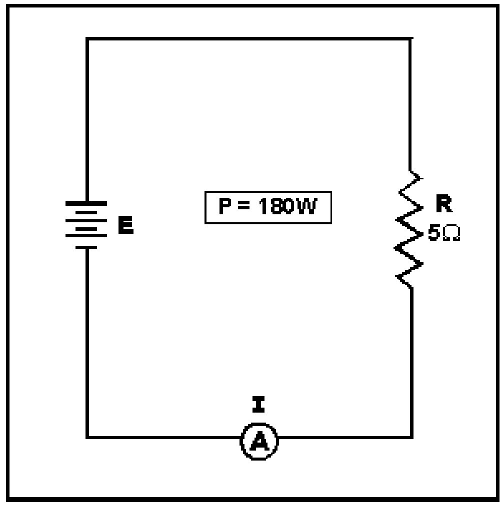


Figure 3-12.—Circuit for computing electrical quantities.

POWER CONVERSION AND EFFICIENCY

The term power consumption is common in the electrical field. It is applied to the use of power in the same sense that gasoline consumption is applied to the use of fuel in an automobile.

Another common term is power conversion. Power is used by electrical devices and is converted from one form of energy to another. An electrical motor converts electrical energy to mechanical energy. An electric light bulb converts electrical energy into light energy and an electric range converts electrical energy into heat energy. Power used by electrical devices is measured in energy. This practical unit of electrical energy is equal to 1 watt of power used continuously for 1 hour. The term kilowatt hour (kWh) is used more extensively on a daily basis and is equal to 1,000 watt-hours.

The EFFICIENCY of an electrical device is the ratio of power converted to useful energy divided by the power consumed by the device. This number will always be less than one (1.00) because of the losses in any electrical device. If a device has an efficiency rating of .95, it effectively transforms 95 watts into useful energy for every 100 watts of input power. The other 5 watts are lost to heat, or other losses which cannot be used.

Calculating the amount of power converted by an electrical device is a simple matter. You need to know the length of time the device is operated and the input power or horsepower rating. Horsepower, a unit of work, is often found as a rating on electrical motors. One horsepower is equal to 746 watts. Example: A 3/4-hp motor operates 8 hours a day. How much power is converted by the motor per month? How many kWh does this represent?

Given: $t = 8$ hrs x 30 days

$P = 3/4$ hp

Solution: Convert horsepower to watts

$P =$ hp x 746 watts

$P = 3/4$ x 746 watts

$$P = 559 \text{ watts}$$

Convert watts to watt-hours

$$P = \text{work x time}$$

$$P = 559 \text{ watts x } 8 \text{ x } 30$$

$$P = 134{,}000 \text{ watt-hours per month}$$

(NOTE: These figures are rounded to the nearest 1000.)

To convert to kWh

$$P = \frac{\text{Power in watt-hours}}{1000}$$

$$P = \frac{134{,}000 \text{ in watt-hours}}{1000}$$

$$P = 134 \text{ kWh}$$

If the motor actually uses 137 kWh per month, what is the efficiency of the motor?

Given: Power converted = 134 kWh per month

Power used = 137 kWh per month

Solution:

$$EFF = \frac{\text{Power converted}}{\text{Power used}}$$

$$EFF = \frac{134 \text{ kWh per month}}{137 \text{ kWh per month}}$$

$$EFF = .978 \text{ (Rounded to three figures)}$$

Q15. How much power is converted by a 1-horsepower motor in 12 hours?

Q16. What is the efficiency of the motor if it actually uses 9.5 kWh in 12 hours?

SERIES DC CIRCUITS

When two unequal charges are connected by a conductor, a complete pathway for current exists. An electric circuit is a complete conducting pathway. It consists not only of the conductor, but also includes the path through the voltage source. Inside the voltage source current flows from the positive terminal, through the source, emerging at the negative terminal.

SERIES CIRCUIT CHARACTERISTICS

A SERIES CIRCUIT is defined as a circuit that contains only ONE PATH for current flow. To compare the basic circuit that has been discussed and a more complex series circuit, figure 3-13 shows two circuits. The basic circuit has only one lamp and the series circuit has three lamps connected in series.

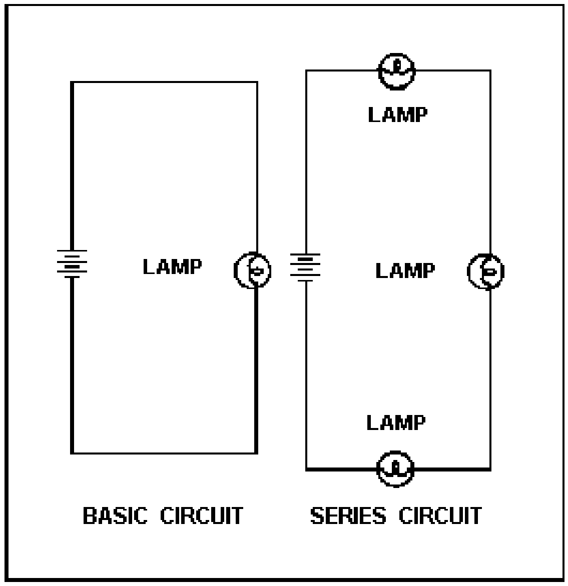


Figure 3-13.—Comparison of basic and series circuits.

Resistance in a Series Circuit

Referring to figure 3-13, the current in a series circuit must flow through each lamp to complete the electrical path in the circuit. Each additional lamp offers added resistance. In a series circuit, THE TOTAL CIRCUIT RESISTANCE (R_T) IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTANCES.

As an equation: $\mathbf{R_T = R_1 + R_2 + R_3 + \ldots R_n}$

NOTE: The subscript n denotes any number of additional resistances that might be in the equation.

Example: In figure 3-14 a series circuit consisting of three resistors: one of 10 ohms, one of 15 ohms, and one of 30 ohms, is shown. A voltage source provides 110 volts. What is the total resistance?

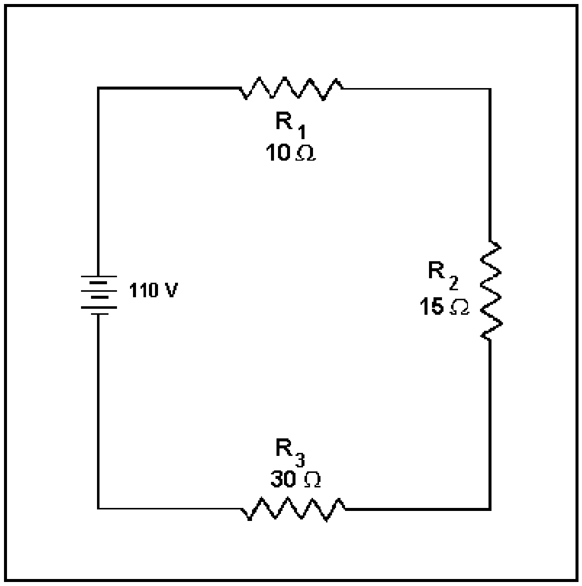


Figure 3-14.—Solving for total resistance in a series circuit.

Given: $R_1 = 10$ ohms
$R_2 = 15$ ohms
$R_3 = 30$ ohms

Soulution: $R_T = R_1 + R_2 + R_3$
$R_T = 10 \text{ ohms} + 15 \text{ ohms} + 30 \text{ ohms}$
$R_T = 55$ ohms

In some circuit applications, the total resistance is known and the value of one of the circuit resistors has to be determined. The equation $R_T = R_1 + R_2 + R_3$ can be transposed to solve for the value of the unknown resistance.

Example: In figure 3-15 the total resistance of a circuit containing three resistors is 40 ohms. Two of the circuit resistors are 10 ohms each. Calculate the value of the third resistor (R_3).

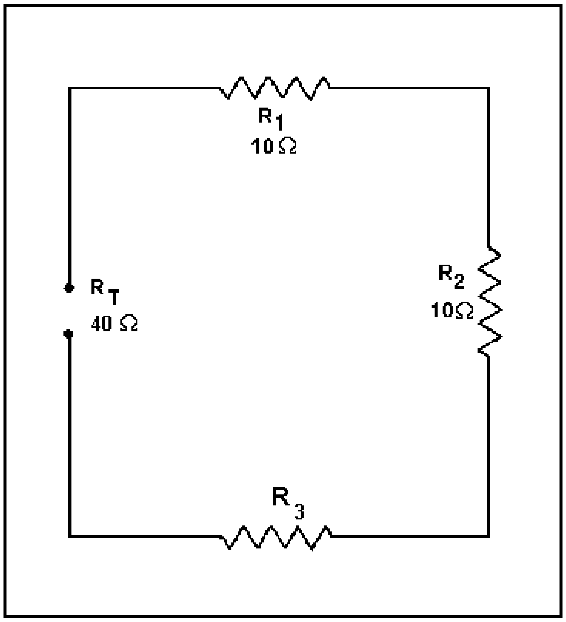


Figure 3-15.—Calculating the value of one resistance in a series circuit.

Given:

$R_1 = 40$ ohms
$R_2 = 10$ ohms
$R_3 = 10$ ohms

Solution:

$$R_T = R_1 + R_2 + R_3$$

(Subtract $R_1 + R_2$ from both sides of the equation.)

$$R_T - R_1 - R_2 = R_3$$
$$R_3 = R_T - R_1 - R_2$$
$$R_3 = 40 \text{ ohms} - 10 \text{ ohms} - 10 \text{ ohms}$$
$$R_3 = 40 \text{ ohms} - 20 \text{ ohms}$$
$$R_3 = 20 \text{ ohms}$$

Current in a Series Circuit

Since there is only one path for current in a series circuit, the same current must flow through each component of the circuit. To determine the current in a series circuit, only the current through one of the components need be known.

The fact that the same current flows through each component of a series circuit can be verified by inserting meters into the circuit at various points, as shown in figure 3-16. If this were done, each meter would be found to indicate the same value of current.

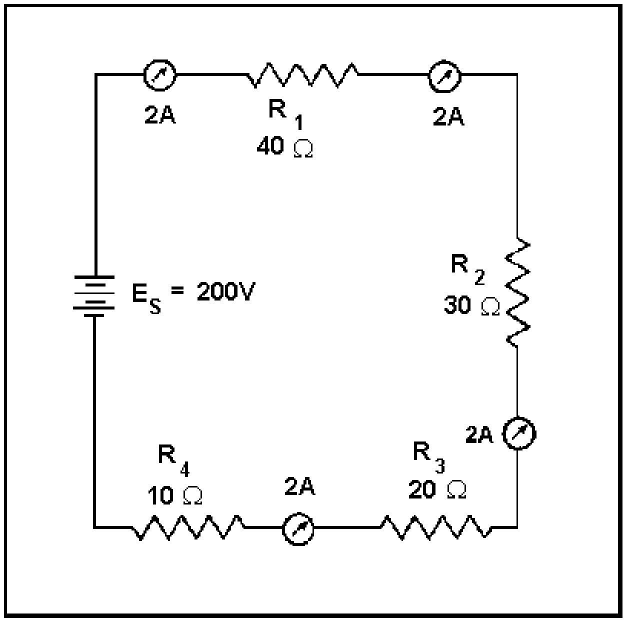


Figure 3-16.—Current in a series circuit.

Voltage in a Series Circuit

The voltage dropped across the resistor in a circuit consisting of a single resistor and a voltage source is the total voltage across the circuit and is equal to the applied voltage. The total voltage across a series circuit that consists of more than one resistor is also equal to the applied voltage, but consists of the sum of the individual resistor voltage drops. In any series circuit, the SUM of the resistor voltage drops must equal the source voltage. This statement can be proven by an examination of the circuit shown in figure 3-17. In this circuit a source potential (E_T) of 20 volts is dropped across a series circuit consisting of two 5-ohm resistors. The total resistance of the circuit (R_T) is equal to the sum of the two individual resistances, or 10 ohms. Using Ohm's law the circuit current may be calculated as follows:

Given: $E_T = 20 \text{ volts}$
$R_T = 10 \text{ ohms}$

Solution: $$I_T = \frac{E_T}{R_T}$$

$$I_T = \frac{20 \text{ volts}}{10 \text{ ohms}}$$

$$I_T = 2 \text{ amps}$$

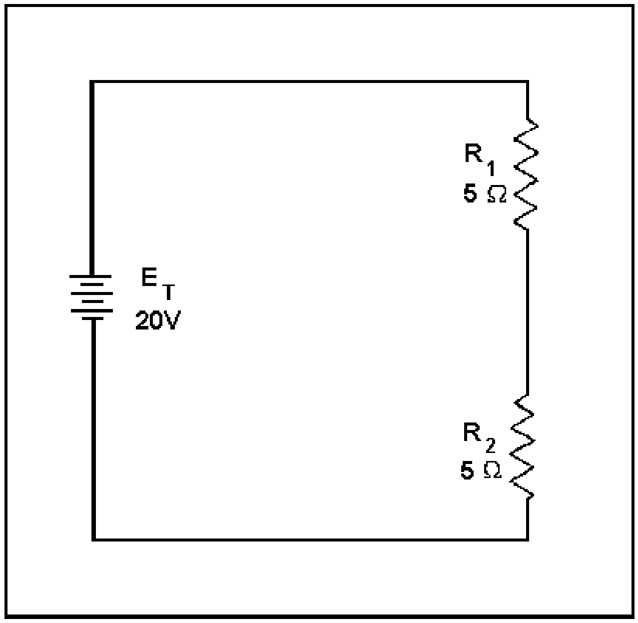


Figure 3-17.—Calculating individual voltage drops in a series circuit.

Since the value of the resistors is known to be 5 ohms each, and the current through the resistors is known to be 2 amperes, the voltage drops across the resistors can be calculated. The voltage (E_1) across R_1 is therefore:

Given: $I_1 = 2$ amperes
$R_1 = 5$ ohms

Solution: $E_1 = I_1 \times R_1$
$E_1 = 2 \text{ amperes} \times 5 \text{ ohms}$
$E_1 = 10 \text{ volts}$

By inspecting the circuit, you can see that R_2 is the same ohmic value as R_1 and carries the same current. The voltage drop across R_2 is therefore also equal to 10 volts. Adding these two 10-volts drops together gives a total drop of 20 volts, exactly equal to the applied voltage. For a series circuit then:

$$E_T = E_1 = E_2 + E_3 = \ldots E_n$$

Example: A series circuit consists of three resistors having values of 20 ohms, 30 ohms, and 50 ohms, respectively. Find the applied voltage if the current through the 30 ohm resistor is 2 amps. (The abbreviation amp is commonly used for ampere.)

To solve the problem, a circuit diagram is first drawn and labeled (fig 3-18).

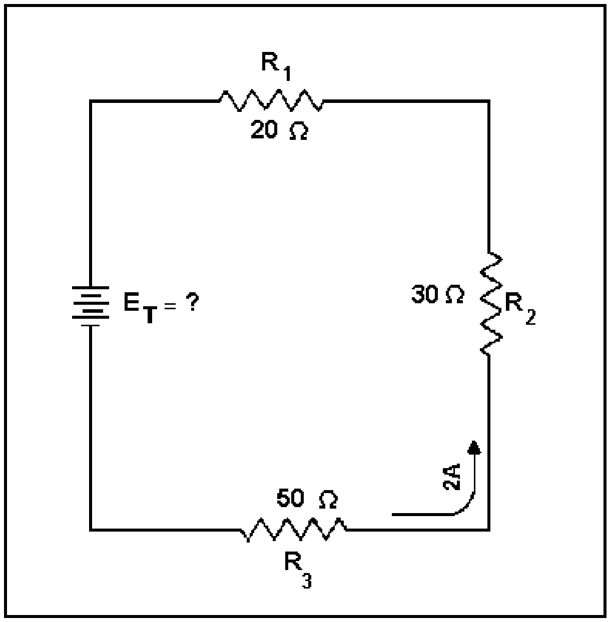


Figure 3-18.—Solving for applied voltage in a series circuit.

Given:

$R_1 = 20$ ohms
$R_2 = 30$ ohms
$R_3 = 50$ ohms
$I = 2$ amps

Solution:

$E_T = E_1 + E_2 + E_3$
$E_1 = R_1 \times I_1$ (I_1= The current through resistor R_1)
$E_2 = R_2 \times I_2$
$E_3 = R_3 \times I_3$

Substituting:

$$E_T = (R_1 \times I_1) + (R_2 \times I_2) + (R_3 \times I_3)$$

$$E_T = (20 \text{ ohms} \times 2 \text{ amps}) + (30 \text{ ohms} \times 2 \text{ amps}) + (50 \text{ ohms} \times 2 \text{ amps})$$

$$E_T = 40 \text{ volts} + 60 \text{ volts} + 100 \text{ volts}$$

$$E_T = 200 \text{ volts}$$

NOTE: When you use Ohm's law, the quantities for the equation MUST be taken from the SAME part of the circuit. In the above example the voltage across R_2 was computed using the current through R_2 and the resistance of R_2.

The value of the voltage dropped by a resistor is determined by the applied voltage and is in proportion to the circuit resistances. The voltage drops that occur in a series circuit are in direct proportion to the resistances. This is the result of having the same current flow through each resistor—the larger the ohmic value of the resistor, the larger the voltage drop across it.

Q17. A series circuit consisting of three resistors has a current of 3 amps. If R_1 = 20 ohms, R_2= 60 ohms, and R_3 = 80 ohms, what is the (a) total resistance and (b) source voltage of the circuit?

Q18. What is the voltage dropped by each resistor of the circuit described in question 17?

Q19. If the current was increased to 4 amps, what would be the voltage drop across each resistor in the circuit described in question 17?

Q20. What would have to be done to the circuit described in question 17 to increase the current to 4 amps?

Power in a Series Circuit

Each of the resistors in a series circuit consumes power which is dissipated in the form of heat. Since this power must come from the source, the total power must be equal to the power consumed by the circuit resistances. In a series circuit the total power is equal to the SUM of the power dissipated by the individual resistors. Total power (P_T) is equal to:

$$P_T = P_1 + P_2 + P_3 \ldots P_n$$

Example: A series circuit consists of three resistors having values of 5 ohms, 10 ohms, and 15 ohms. Find the total power when 120 volts is applied to the circuit. (See fig. 3-19.)

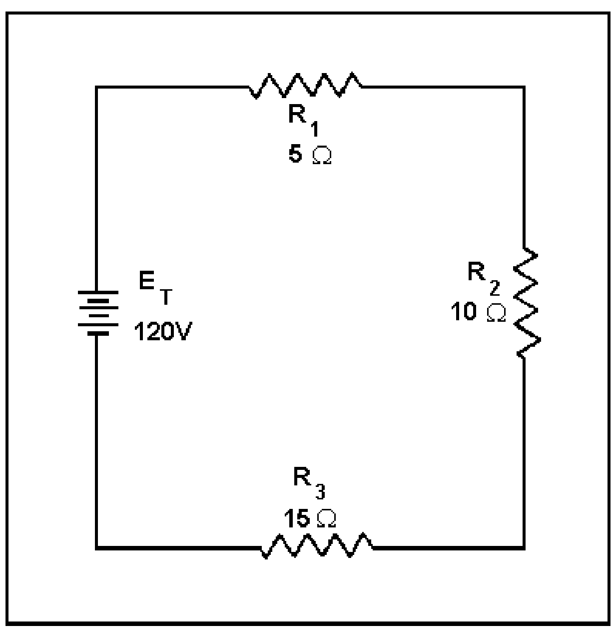


Figure 3-19.—Solving for total power in a series circuit.

Given:

$$R_1 = 5 \text{ ohms}$$
$$R_2 = 10 \text{ ohms}$$
$$R_3 = 15 \text{ ohms}$$
$$E = 120 \text{ volts}$$

Solution: The total resistance is found first.

$$R_T = R_1 + R_2 + R_3$$
$$R_T = 5 \text{ ohms} + 10 \text{ ohms} + 15 \text{ ohms}$$
$$R_T = 30 \text{ ohms}$$

By using the total resistance and the applied voltage, the circuit current is calculated.

$$I = \frac{E_T}{R_T}$$

$$I = \frac{120 \text{ volts}}{30 \text{ ohms}}$$

$$I = 4 \text{ amps}$$

By means of the power formulas, the power can be calculated for each resistor:

$$\text{For } R_1: \quad P_1 = I^2 \times R_1$$
$$P_1 = (4 \text{ amps})^2 \times 5 \text{ ohms}$$
$$P_1 = 80 \text{ watts}$$

$$\text{For } R_2: \quad P_2 = I^2 \times R_2$$
$$P_2 = (4 \text{ amps})^2 \times 10 \text{ ohms}$$
$$P_2 = 160 \text{ watts}$$

$$\text{For } R_3: \quad P_3 = I^2 \times R_3$$
$$P_3 = (4 \text{ amps})^2 \times 15 \text{ ohms}$$
$$P_3 = 240 \text{ watts}$$

For total power:

$$P_T = P_1 + P_2 + P_3$$
$$P_T = 80 \text{ watts} + 160 \text{ watts} + 240 \text{ watts}$$
$$P_T = 480 \text{ watts}$$

To check the answer, the total power delivered by the source can be calculated:

$$P_{source} = I_{source} \times E_{source}$$
$$P_{source} = 4 \text{ amps} \times 120 \text{ volts}$$
$$P_{source} = 480 \text{ watts}$$

The total power is equal to the sum of the power used by the individual resistors.

SUMMARY OF CHARACTERISTICS

The important factors governing the operation of a series circuit are listed below. These factors have been set up as a group of rules so that they may be easily studied. These rules must be completely understood before the study of more advanced circuit theory is undertaken.

Rules for Series DC Circuits

1. The same current flows through each part of a series circuit.
2. The total resistance of a series circuit is equal to the sum of the individual resistances.
3. The total voltage across a series circuit is equal to the sum of the individual voltage drops.
4. The voltage drop across a resistor in a series circuit is proportional to the ohmic value of the resistor.
5. The total power in a series circuit is equal to the sum of the individual powers used by each circuit component.

SERIES CIRCUIT ANALYSIS

To establish a procedure for solving series circuits, the following sample problems will be solved.

Example: Three resistors of 5 ohms, 10 ohms, and 15 ohms are connected in series with a power source of 90 volts as shown in figure 3-20. Find the total resistance, circuit current, voltage drop of each resistor, power of each resistor, and total power of the circuit.

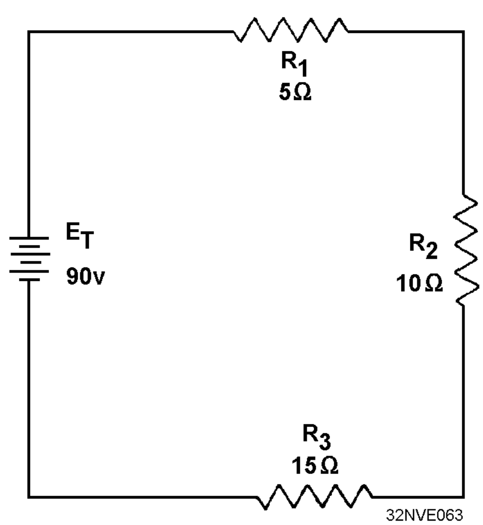


Figure 3-20.—Solving for various values in a series circuit.

In solving the circuit the total resistance will be found first. Next, the circuit current will be calculated. Once the current is known, the voltage drops and power dissipations can be calculated.

Given:

$R_1 = 5$ ohms
$R_2 = 10$ ohms
$R_3 = 15$ ohms
$E = 90$ volts

Solution:

$R_T = R_1 + R_2 + R_3$
$R_T = 5$ ohms $+ 10$ ohms $+ 15$ ohms
$R_T = 30$ ohms

$$I = \frac{E_T}{R_T}$$

$$I = \frac{90 \text{ volts}}{30 \text{ ohms}}$$

$I = 3$ amps

$E_1 = IR_1$
$E_1 = 3$ amperes $\times$ 5 ohms
$E_1 = 15$ volts

$E_2 = IR_2$
$E_2 = 3$ amperes $\times$ 10 ohms
$E_2 = 30$ volts

$E_3 = IR_3$
$E_3 = 3$ amperes $\times$ 15 ohms
$E_3 = 45$ volts

$P_1 = I \times E_1$
$P_1 = 3$ amperes $\times$ 15 volts
$P_1 = 45$ watts

$P_2 = I \times E_2$
$P_2 = 3$ amperes $\times$ 30 volts
$P_2 = 90$ watts

$$P_3 = I \times E_3$$
$$P_3 = 3 \text{ amperes} \times 45 \text{ volts}$$
$$P_3 = 135 \text{ watts}$$

$$P_T = E_1 \times I$$
$$P_T = 90 \text{ volts} \times 3 \text{ amps}$$
$$P_T = 270 \text{ watts}$$

or

$$P_T = P_1 + P_2 + P_3$$
$$P_T = 45 \text{ watts} + 90 \text{ watts} + 135 \text{ watts}$$
$$P_T = 270 \text{ watts}$$

Example: Four resistors, R_1 = 10 ohms, R_2 = 10 ohms, R_3 = 50 ohms, and R_4 = 30 ohms, are connected in series with a power source as shown in figure 3-21. The current through the circuit is 1/2 ampere.

a. What is the battery voltage?

b. What is the voltage across each resistor?

c. What is the power expended in each resistor?

d. What is the total power?

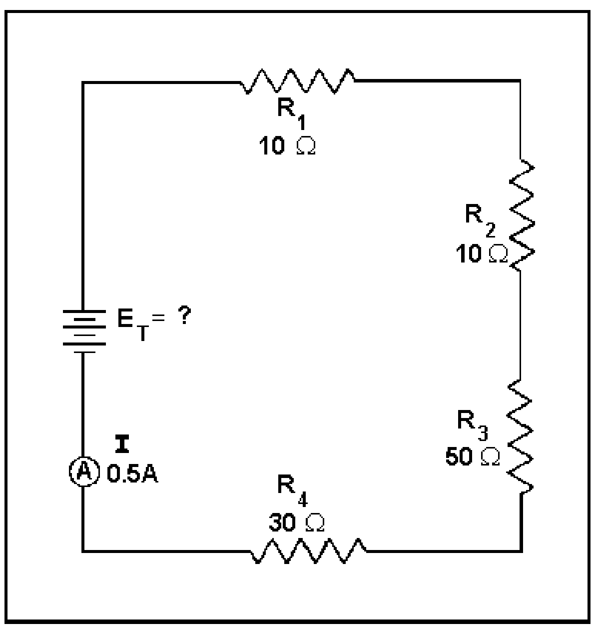


Figure 3-21.—Computing series circuit values.

Given:

$$R_1 = 10 \text{ ohms}$$
$$R_2 = 10 \text{ ohms}$$
$$R_3 = 50 \text{ ohms}$$
$$R_4 = 30 \text{ ohms}$$
$$I = 0.5 \text{ amps}$$

Solution (a):

$$E_T = IR_T$$
$$R_T = R_1 + R_2 + R_3 + R_4$$
$$R_T = 10 \text{ ohms} + 10 \text{ ohms} + 50 \text{ ohms} + 30 \text{ ohms}$$
$$R_T = 100 \text{ ohms}$$
$$E_T = 0.5 \text{ amps} \times 100 \text{ ohms}$$
$$E_T = 50 \text{ volts}$$

Solution (b):

$$E_1 = IR_1$$
$$E_1 = 0.5 \text{ amperes} \times 10 \text{ ohms}$$
$$E_1 = 5 \text{ volts}$$

$$E_2 = IR_2$$
$$E_2 = 0.5 \text{ amperes} \times 10 \text{ ohms}$$
$$E_2 = 5 \text{ volts}$$

$$E_3 = IR_3$$
$$E_3 = 0.5 \text{ amperes} \times 50 \text{ ohms}$$
$$E_3 = 25 \text{ volts}$$

$$E_4 = IR_4$$
$$E_4 = 0.5 \text{ amperes} \times 30 \text{ ohms}$$
$$E_4 = 15 \text{ volts}$$

Solution (c):

$$P_1 = IE_1$$
$$P_1 = 0.5 \text{ amperes} \times 5 \text{ volts}$$
$$P_1 = 2.5 \text{ watts}$$

$$P_2 = IE_2$$
$$P_2 = 0.5 \text{ amperes} \times 5 \text{ volts}$$
$$P_2 = 2.5 \text{ watts}$$

$$P_3 = IE_3$$
$$P_3 = 0.5 \text{ amperes} \times 25 \text{ volts}$$
$$P_3 = 12.5 \text{ watts}$$

$$P_4 = IE_4$$
$$P_4 = 0.5 \text{ amperes} \times 15 \text{ volts}$$
$$P_4 = 7.5 \text{ watts}$$

Solution (d):

$$P_T = P_1 + P_2 + P_3 + P_4$$
$$P_T = 2.5 \text{ watts} + 2.5 \text{ watts} + 12.5 \text{ watts} + 7.5 \text{ watts}$$
$$P_T = 25 \text{ watts}$$

or

$$P_T = IE_T$$
$$P_T = 0.5 \text{ amperes} \times 50 \text{ volts}$$
$$P_T = 25 \text{ watts}$$

or

$$P_T = \frac{{E_T}^2}{R_T}$$

$$P_T = \frac{(50 \text{ volts})^2}{100 \text{ ohms}}$$

$$P_T = \frac{2500 \text{ volts}}{100 \text{ ohms}}$$

$$P_T = 25 \text{ watts}$$

An important fact to keep in mind when applying Ohm’s law to a series circuit is to consider whether the values used are component values or total values. When the information available enables the use of Ohm’s law to find total resistance, total voltage, and total current, total values must be inserted into the formula. To find total resistance:

$$R_T = \frac{E_T}{I_T}$$

To find total voltage:

$$E_T = I_T = R_T$$

To find total current:

$$I_T = \frac{E_T}{R_T}$$

NOTE: I_T is equal to I in a series circuit. However, the distinction between I_T and I in the formula should be noted. The reason for this is that future circuits may have several currents, and it will be necessary to differentiate between I_T and other currents.

To compute any quantity (E, I, R, or P) associated with a single given resistor, the values used in the formula must be obtained from that particular resistor. For example, to find the value of an unknown resistance, the voltage across and the current through that particular resistor must be used.

To find the value of a resistor:

$$R = \frac{E_R}{I_R}$$

To find the voltage drop across a resistor:

$$E_R = I_R \times R$$

To find current through a resistor:

$$I_R = \frac{E_R}{R}$$

Q21. A series circuit consists of two resistors in series. R_1 = 25 ohms and R_2 = 30 ohms. The circuit current is 6 amps. What is the (a) source voltage, (b) voltage dropped by each resistor, (c) total power, and (d) power used by each resistor?

KIRCHHOFF'S VOLTAGE LAW

In 1847, G. R. Kirchhoff extended the use of Ohm's law by developing a simple concept concerning the voltages contained in a series circuit loop. Kirchhoff's voltage law states:

"The algebraic sum of the voltage drops in any closed path in a circuit and the electromotive forces in that path is equal to zero."

To state Kirchhoff's law another way, the voltage drops and voltage sources in a circuit are equal at any given moment in time. If the voltage sources are assumed to have one sign (positive or negative) at that instant and the voltage drops are assumed to have the opposite sign, the result of adding the voltage sources and voltage drops will be zero.

NOTE: The terms electromotive force and emf are used when explaining Kirchhoff's law because Kirchhoff's law is used in alternating current circuits (covered in Module 2). In applying Kirchhoff's law to direct current circuits, the terms electromotive force and emf apply to voltage sources such as batteries or power supplies.

Through the use of Kirchhoff's law, circuit problems can be solved which would be difficult, and often impossible, with knowledge of Ohm's law alone. When Kirchhoff's law is properly applied, an equation can be set up for a closed loop and the unknown circuit values can be calculated.

POLARITY OF VOLTAGE

To apply Kirchhoff's voltage law, the meaning of voltage polarity must be understood.

In the circuit shown in figure 3-22, the current is shown flowing in a counterclockwise direction. Notice that the end of resistor R_1, into which the current flows, is marked NEGATIVE (−). The end of R_1 at which the current leaves is marked POSITIVE (+). These polarity markings are used to show that the end of R_1 into which the current flows is at a higher negative potential than the end of the resistor at which the current leaves. Point A is more negative than point B.

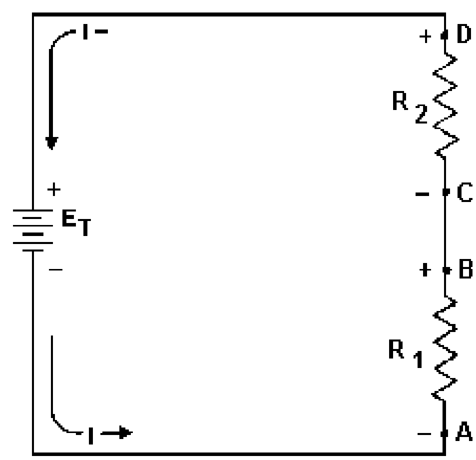


Figure 3-22.—Voltage polarities.

Point C, which is at the same potential as point B, is labeled negative. This is to indicate that point C is more negative than point D. To say a point is positive (or negative) without stating what the polarity is based upon has no meaning. In working with Kirchhoff's law, positive and negative polarities are assigned in the direction of current flow.

APPLICATION OF KIRCHHOFF'S VOLTAGE LAW

Kirchhoff's voltage law can be written as an equation, as shown below:

$$E_a + E_b + E_c + \ldots E_n = 0$$

where E_a, E_b, etc., are the voltage drops or emf's around any closed circuit loop. To set up the equation for an actual circuit, the following procedure is used.

1. Assume a direction of current through the circuit. (The correct direction is desirable but not necessary.)
2. Using the assumed direction of current, assign polarities to all resistors through which the current flows.
3. Place the correct polarities on any sources included in the circuit.
4. Starting at any point in the circuit, trace around the circuit, writing down the amount and polarity of the voltage across each component in succession. The polarity used is the sign AFTER the assumed current has passed through the component. Stop when the point at which the trace was started is reached.
5. Place these voltages, with their polarities, into the equation and solve for the desired quantity.

Example: Three resistors are connected across a 50-volt source. What is the voltage across the third resistor if the voltage drops across the first two resistors are 25 volts and 15 volts?

Solution: First, a diagram, such as the one shown in figure 3-23, is drawn. Next, a direction of current is assumed (as shown). Using this current, the polarity markings are placed at each end of each resistor and also on the terminals of the source. Starting at point A, trace around the circuit in the direction of current flow, recording the voltage and polarity of each component. Starting at point A and using the components from the circuit:

$$(+E_x) + (+E_2) + (+E_1) + (-E_A) = 0$$

Substituting values from the circuit:

$$E_x + 15 \text{ volts} + 25 \text{ volts} - 50 \text{ volts} = 0$$
$$E_x - 10 \text{ volts} = 0$$
$$E_x = 10 \text{ volts}$$

The unknown voltage (E_x) is found to be 10 volts

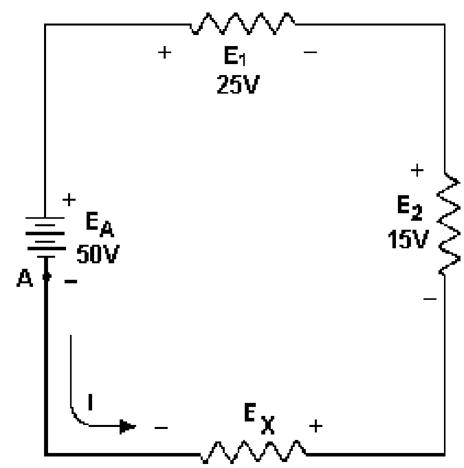


Figure 3-23.—Determining unknown voltage in a series circuit.

Using the same idea as above, you can solve a problem in which the current is the unknown quantity.

Example: A circuit having a source voltage of 60 volts contains three resistors of 5 ohms, 10 ohms, and 15 ohms. Find the circuit current.

Solution: Draw and label the circuit (fig. 3-24). Establish a direction of current flow and assign polarities. Next, starting at any point—point A will be used in this example—write out the loop equation.

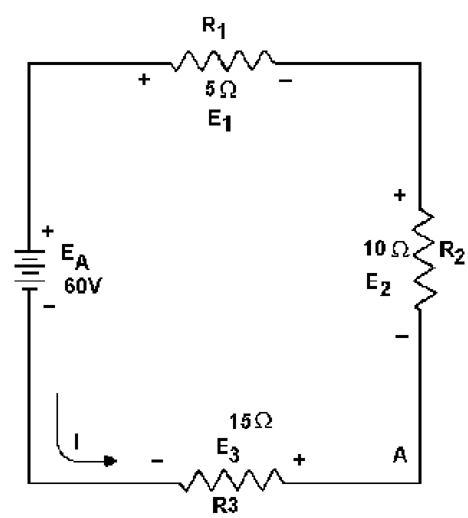


Figure 3-24.—Correct direction of assumed current.

Basic equation:
$$E_2 + E_1 + E_A + E_3 = 0$$

Since E=IR, by substitution:
$$(I \times R_2) + (I \times R_1) + E_A + (I \times R_3) = 0$$

Substituting Values:
$$(I \times 10 \text{ ohms}) + (I \times 5 \text{ ohms}) + (-60 \text{ volts}) + (I \times 15 \text{ ohms}) = 0$$

Combining like terms:
$$(I \times 30 \text{ ohms}) + (-60 \text{ volts}) = 0$$

$$(I \times 30 \text{ ohms}) = 60 \text{ volts}$$

$$I = \frac{60 \text{ volts}}{30 \text{ ohms}}$$

$$I = 2 \text{ amps}$$

Since the current obtained in the above calculations is a positive 2 amps, the assumed direction of current was correct. To show what happens if the incorrect direction of current is assumed, the problem will be solved as before, but with the opposite direction of current. The circuit is redrawn showing the new direction of current and new polarities in figure 3-25. Starting at point A the loop equation is:

$$E_3 + E_A + E_1 + E_2 = 0$$

$$(I \times R_3) + E_A + (I \times R_1) + (I \times R_2) = 0$$

Substituting Values:
$$(I \times 15 \text{ ohms}) + 60 \text{ volts} + (I \times 5 \text{ ohms}) + (I \times 10 \text{ ohms}) = 0$$

Combining like terms:
$$(I \times 30 \text{ ohms}) + 60 \text{ volts} = 0$$

$$I \times 30 \text{ ohms} = -60 \text{ volts}$$

$$I = \frac{-60 \text{ volts}}{30 \text{ ohms}}$$

$$I = -2 \text{ amps}$$

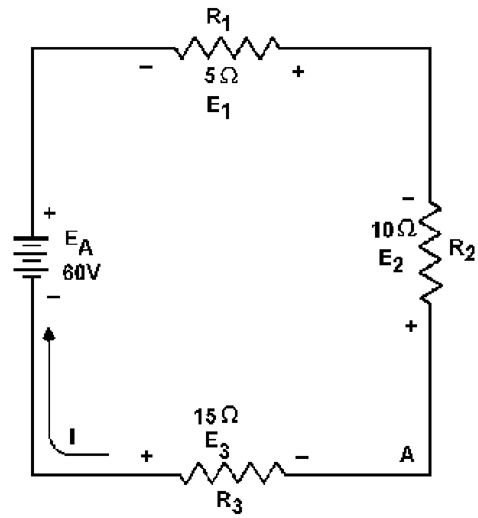


Figure 3-25.—Incorrect direction of assumed current.

Notice that the AMOUNT of current is the same as before. The polarity, however, is NEGATIVE. The negative polarity simply indicates the wrong direction of current was assumed. Should it be necessary to use this current in further calculations on the circuit using Kirchhoff's law, the negative polarity should be retained in the calculations.

Series Aiding and Opposing Sources

In many practical applications a circuit may contain more than one source of emf. Sources of emf that cause current to flow in the same direction are considered to be SERIES AIDING and the voltages are added. Sources of emf that would tend to force current in opposite directions are said to be SERIES OPPOSING, and the effective source voltage is the difference between the opposing voltages. When two opposing sources are inserted into a circuit current flow would be in a direction determined by the larger source. Examples of series aiding and opposing sources are shown in figure 3-26.

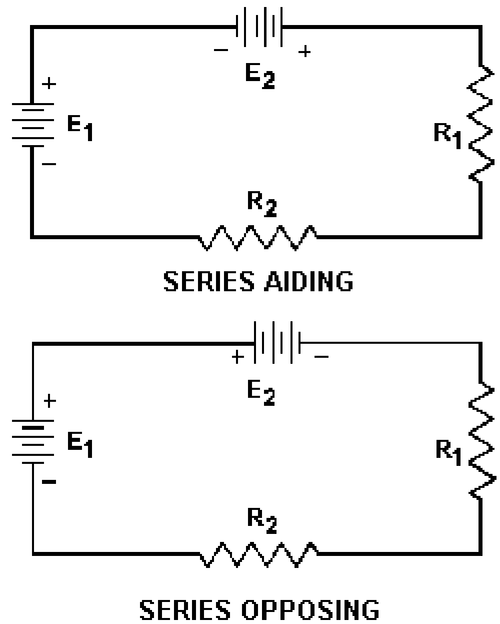


Figure 3-26.—Aiding and opposing sources.

A simple solution may be obtained for a multiple-source circuit through the use of Kirchhoff's voltage law. In applying this method, the same procedure is used for the multiple-source circuit as was used above for the single-source circuit. This is demonstrated by the following example.

Example: Using Kirchhoff's voltage equation, find the amount of current in the circuit shown in fig 3-27.

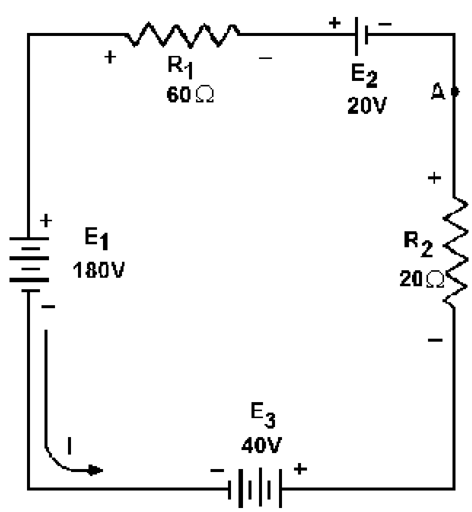


Figure 3-27.-Solving for circuit current using Kirchhoff's voltage equation.

Solution: As before, a direction of current flow is assumed and polarity signs are placed on the drawing. The loop equation will be started at point A.

$$E_2 + E_{R1} + E_1 + E_3 + E_{R2} = 0$$

$$20 \text{ volts} + (I \times 60 \text{ ohms}) + (-180 \text{ volts}) + 40 \text{ volts} + (I \times 20 \text{ ohms}) = 0$$

$$20 \text{ volts} - 180 \text{ volts} + 40 \text{ volts} + (I \times 60 \text{ ohms}) + (I \times 20 \text{ ohms}) = 0$$

$$-120 \text{ volts} + (I \times 80 \text{ ohms}) = 0$$

$$I \times 80 \text{ ohms} = 120 \text{ volts}$$

$$I = \frac{120 \text{ volts}}{80 \text{ ohms}}$$

$$I = 1.5 \text{ amps}$$

Q22. When using Kirchhoff's voltage law, how are voltage polarities assigned to the voltage drops across resistors?

Q23. Refer to figure 3-27, if R_1 was changed to a 40-ohm resistor, what would be the value of circuit current (I_T)?

Q24. Refer to figure 3-27. What is the effective source voltage of the circuit using the 40-ohm resistor?

CIRCUIT TERMS AND CHARACTERISTICS

Before you learn about the types of circuits other than the series circuit, you should become familiar with some of the terms and characteristics used in electrical circuits. These terms and characteristics will be used throughout your study of electricity and electronics.

REFERENCE POINT

A reference point is an arbitrarily chosen point to which all other points in the circuit are compared. In series circuits, any point can be chosen as a reference and the electrical potential at all other points can be determined in reference to that point. In figure 3-28 point A shall be considered the reference point. Each series resistor in the illustrated circuit is of equal value. The applied voltage is equally distributed across each resistor. The potential at point B is 25 volts more positive than at point A. Points C and D are 50 volts and 75 volts more positive than point A respectively.

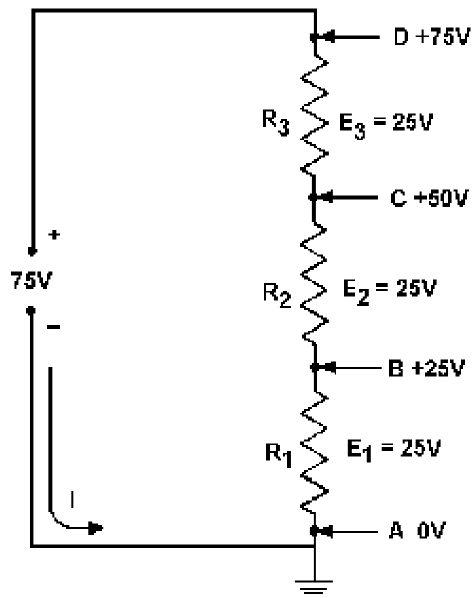


Figure 3-28.—Reference points in a series circuit.

When point B is used as the reference, as in figure 3-29, point D would be positive 50 volts in respect to the new reference point. The former reference point, A, is 25 volts negative in respect to point B.

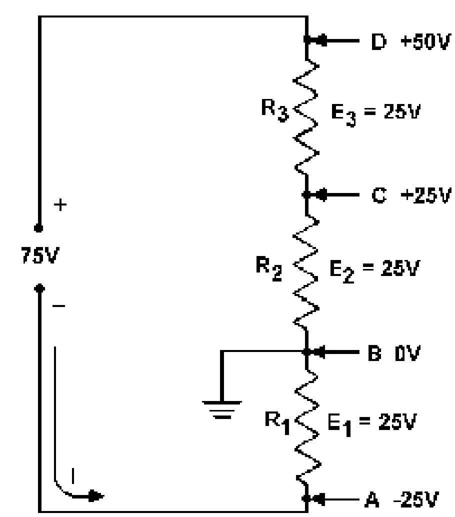


Figure 3-29.—Determining potentials with respect to a reference point.

As in the previous circuit illustration, the reference point of a circuit is always considered to be at zero potential. Since the earth (ground) is said to be at a zero potential, the term GROUND is used to denote a common electrical point of zero potential. In figure 3-30, point A is the zero reference, or ground, and the symbol for ground is shown connected to point A. Point C is 75 volts positive in respect to ground.

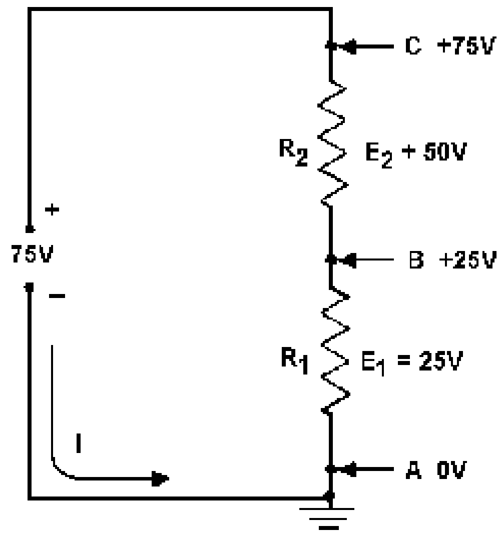


Figure 3-30.—Use of ground symbols.

In most electrical equipment, the metal chassis is the common ground for the many electrical circuits. When each electrical circuit is completed, common points of a circuit at zero potential are connected directly to the metal chassis, thereby eliminating a large amount of connecting wire. The electrons pass through the metal chassis (a conductor) to reach other points of the circuit. An example of a chassis grounded circuit is illustrated in figure 3-31.

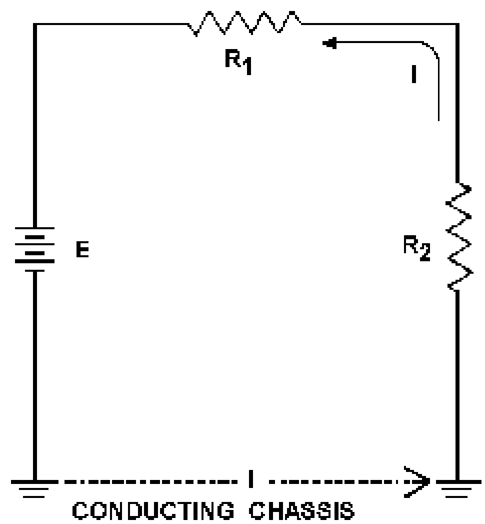


Figure 3-31.—Ground used as a conductor.

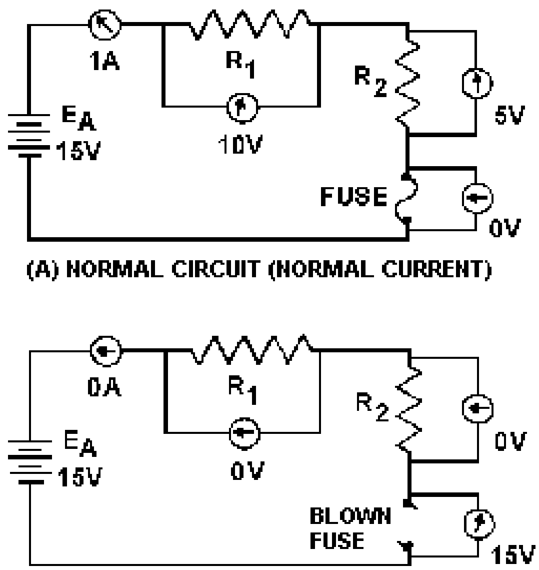
Most voltage measurements used to check proper circuit operation in electrical equipment are taken in respect to ground. One meter lead is attached to a grounded point and the other meter lead is moved to various test points. Circuit measurement is explained in more detail in NEETS Module 3.

OPEN CIRCUIT

A circuit is said to be OPEN when a break exists in a complete conducting pathway. Although an open occurs when a switch is used to deenergize a circuit, an open may also develop accidentally. To restore a circuit to proper operation, the open must be located, its cause determined, and repairs made.

Sometimes an open can be located visually by a close inspection of the circuit components. Defective components, such as burned out resistors, can usually be discovered by this method. Others, such as a break in wire covered by insulation or the melted element of an enclosed fuse, are not visible to the eye. Under such conditions, the understanding of the effect an open has on circuit conditions enables a technician to make use of test equipment to locate the open component.

In figure 3-32, the series circuit consists of two resistors and a fuse. Notice the effects on circuit conditions when the fuse opens.



(A) NORMAL CIRCUIT (NORMAL CURRENT)

(B) OPEN CIRCUIT (DUE TO EXCESSIVE CURRENT)

Figure 3-32.—Normal and open circuit conditions. (A) Normal current; (B) Excessive current.

Current ceases to flow; therefore, there is no longer a voltage drop across the resistors. Each end of the open conducting path becomes an extension of the battery terminals and the voltage felt across the open is equal to the applied voltage (E_A).

An open circuit has INFINITE resistance. INFINITY represents a quantity so large it cannot be measured. The symbol for infinity is ∞. In an open circuit, $R_T = \infty$.

SHORT CIRCUIT

A short circuit is an accidental path of low resistance which passes an abnormally high amount of current. A short circuit exists whenever the resistance of a circuit or the resistance of a part of a circuit drops in value to almost zero ohms. A short often occurs as a result of improper wiring or broken insulation.

In figure 3-33, a short is caused by improper wiring. Note the effect on current flow. Since the resistor has in effect been replaced with a piece of wire, practically all the current flows through the short and very little current flows through the resistor. Electrons flow through the short (a path of almost zero resistance) and the remainder of the circuit by passing through the 10-ohm resistor and the battery. The amount of current flow increases greatly because its resistive path has decreased from 10,010 ohms to 10 ohms. Due to the excessive current flow the 10-ohm resistor becomes heated. As it attempts to dissipate this heat, the resistor will probably be destroyed. Figure 3-34 shows a pictorial wiring diagram, rather than a schematic diagram, to indicate how broken insulation might cause a short circuit.

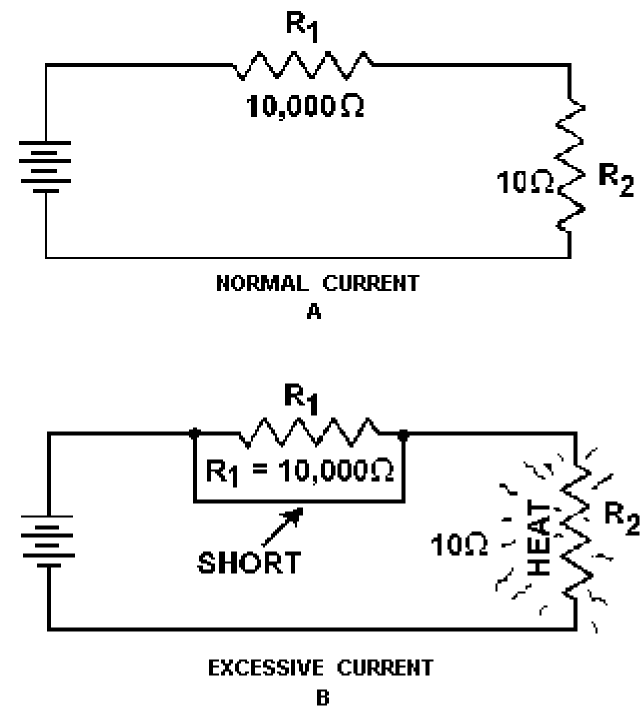


Figure 3-33.—Normal and short circuit conditions.

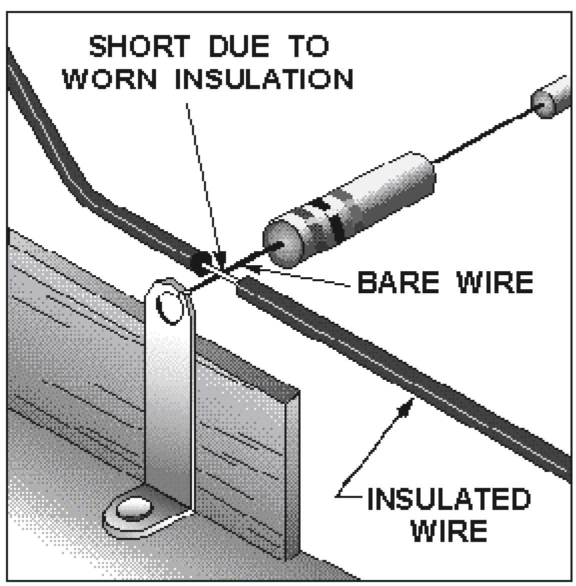


Figure 3-34.—Short due to broken insulation.

SOURCE RESISTANCE

A meter connected across the terminals of a good 1.5-volt battery reads about 1.5 volts. When the same battery is inserted into a complete circuit, the meter reading decreases to something less than 1.5 volts. This difference in terminal voltage is caused by the INTERNAL RESISTANCE of the battery (the opposition to current offered by the electrolyte in the battery). All sources of electromotive force have some form of internal resistance which causes a drop in terminal voltage as current flows through the source.

This principle is illustrated in figure 3-35, where the internal resistance of a battery is shown as R_i. In the schematic, the internal resistance is indicated by an additional resistor in series with the battery. The battery, with its internal resistance, is enclosed within the dotted lines of the schematic diagram. With the switch open, the voltage across the battery terminals reads 15 volts. When the switch is closed, current flow causes voltage drops around the circuit. The circuit current of 2 amperes causes a voltage drop of 2 volts across R_i. The 1-ohm internal battery resistance thereby drops the battery terminal voltage to 13 volts. Internal resistance cannot be measured directly with a meter. An attempt to do this would damage the meter.

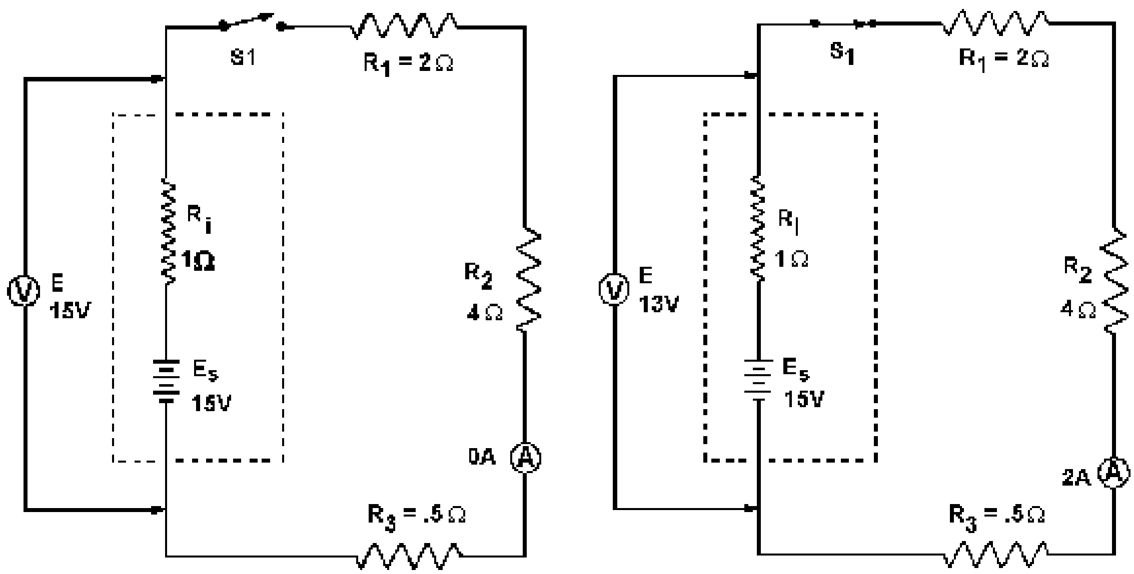
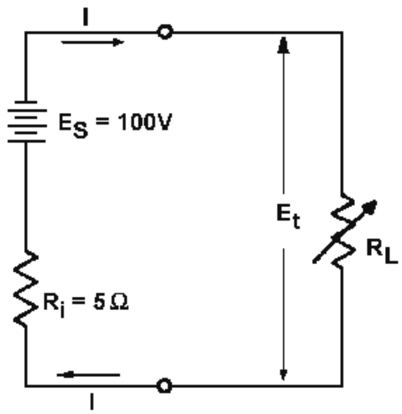


Figure 3-35.—Effect of internal resistance.

The effect of the source resistance on the power output of a dc source may be shown by an analysis of the circuit in figure 3-36. When the variable load resistor (R_L) is set at the zero-ohm position (equivalent to a short circuit), current (I) is calculated using the following formula:

$$I = \frac{E_S}{R_i} = \frac{100 \text{ volts}}{5 \text{ ohms}} = 20 \text{ amperes}$$

This is the maximum current that may be drawn from the source. The terminal voltage across the short circuit is zero volts and all the voltage is across the resistance within the source.

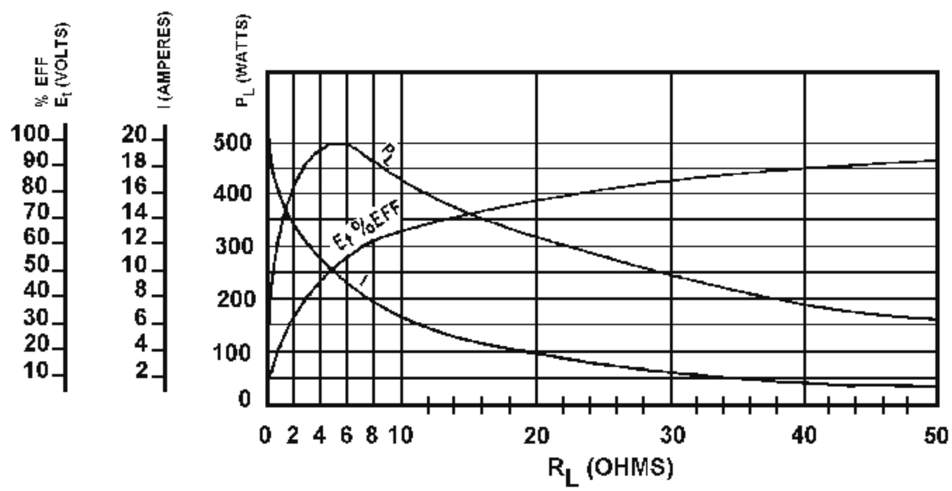


E_S = OPEN - CIRCUIT VOLTAGE OF SOURCE
R_i = INTERNAL RESISTANCE OF SOURCE
E_t = TERMINAL VOLTAGE
R_L = RESISTANCE OF LOAD
P_L = POWER USED IN LOAD
I = CURRENT FROM SOURCE
% EFF. = PERCENTAGE OF EFFICIENCY

(A)
CIRCUIT AND SYMBOL DESIGNATION

R_L	E_t	I	P_L	%EFF.
0	0	20	0	0
1	16.7	16.7	278.9	16.7
2	28.6	14.3	409	28.6
3	37.5	12.5	468.8	37.5
4	44.4	11.1	492.8	44.4
5	50	10	500	50
6	54.5	9.1	496.0	54.5
7	58.3	8.3	483.9	58.3
8	61.6	7.7	474.3	61.6
9	64.3	7.1	456.5	64.3
10	66.7	6.7	446.9	66.7
20	80	4	320	80
30	85.7	2.9	248.5	85.7
40	88.9	2.2	195.6	88.9
50	90.9	1.9	172.7	90.9

(B)
CHART



(C)
GRAPH

Figure 3-36.—Effect of source resistance on power output.

If the load resistance (R_L) were increased (the internal resistance remaining the same), the current drawn from the source would decrease. Consequently, the voltage drop across the internal resistance would decrease. At the same time, the terminal voltage applied across the load would increase and approach a maximum as the current approaches zero amps.

POWER TRANSFER AND EFFICIENCY

Maximum power is transferred from the source to the load when the resistance of the load is equal to the internal resistance of the source. This theory is illustrated in the table and the graph of figure 3-36. When the load resistance is 5 ohms, matching the source resistance, the maximum power of 500 watts is developed in the load.

The efficiency of power transfer (ratio of output power to input power) from the source to the load increases as the load resistance is increased. The efficiency approaches 100 percent as the load resistance approaches a relatively large value compared with that of the source, since less power is lost in the source. The efficiency of power transfer is only 50 percent at the maximum power transfer point (when the load resistance equals the internal resistance of the source). The efficiency of power transfer approaches zero efficiency when the load resistance is relatively small compared with the internal resistance of the source. This is also shown on the chart of figure 3-36.

The problem of a desire for both high efficiency and maximum power transfer is resolved by a compromise between maximum power transfer and high efficiency. Where the amounts of power involved are large and the efficiency is important, the load resistance is made large relative to the source resistance so that the losses are kept small. In this case, the efficiency is high. Where the problem of matching a source to a load is important, as in communications circuits, a strong signal may be more important than a high percentage of efficiency. In such cases, the efficiency of power transfer should be only about 50 percent; however, the power transfer would be the maximum which the source is capable of supplying.

You should now understand the basic concepts of series circuits. The principles which have been presented are of lasting importance. Once equipped with a firm understanding of series circuits, you hold the key to an understanding of the parallel circuits to be presented next.

Q25. A circuit has a source voltage of 100 volts and two 50-ohm resistors connected in series. If the reference point for this circuit is placed between the two resistors, what would be the voltage at the reference point?

Q26. If the reference point in question 25 were connected to ground, what would be the voltage level of the reference point?

Q27. What is an open circuit?

Q28. What is a short circuit?

Q29. Why will a meter indicate more voltage at the battery terminal when the battery is out of a circuit than when the battery is in a circuit?

Q30. What condition gives maximum power transfer from the source to the load?

Q31. What is the efficiency of power transfer in question 30?

Q32. A circuit has a source voltage of 25 volts. The source resistance is 1 ohm and the load resistance is 49 ohms. What is the efficiency of power transfer?

PARALLEL DC CIRCUITS

The discussion of electrical circuits presented up to this point has been concerned with series circuits in which there is only one path for current. There is another basic type of circuit known as the PARALLEL CIRCUIT with which you must become familiar. Where the series circuit has only one path for current, the parallel circuit has more than one path for current.

Ohm's law and Kirchhoff's law apply to all electrical circuits, but the characteristics of a parallel dc circuit are different than those of a series dc circuit.

PARALLEL CIRCUIT CHARACTERISTICS

A PARALLEL CIRCUIT is defined as one having more than one current path connected to a common voltage source. Parallel circuits, therefore, must contain two or more resistances which are not connected in series. An example of a basic parallel circuit is shown in figure 3-37.

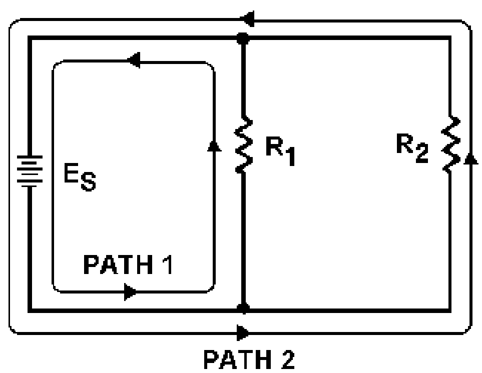


Figure 3-37.—Example of a basic parallel circuit.

Start at the voltage source (E_s) and trace counterclockwise around the circuit. Two complete and separate paths can be identified in which current can flow. One path is traced from the source, through resistance R_1, and back to the source. The other path is from the source, through resistance R_2, and back to the source.

Voltage in a Parallel Circuit

You have seen that the source voltage in a series circuit divides proportionately across each resistor in the circuit. IN A PARALLEL CIRCUIT, THE SAME VOLTAGE IS PRESENT IN EACH BRANCH. (A branch is a section of a circuit that has a complete path for current.) In figure 3-37 this voltage is equal to the applied voltage (E_s). This can be expressed in equation form as:

$$E_S = E_{R1} = E_{R2}$$

Voltage measurements taken across the resistors of a parallel circuit, as illustrated by figure 3-38 verify this equation. Each meter indicates the same amount of voltage. Notice that the voltage across each resistor is the same as the applied voltage.

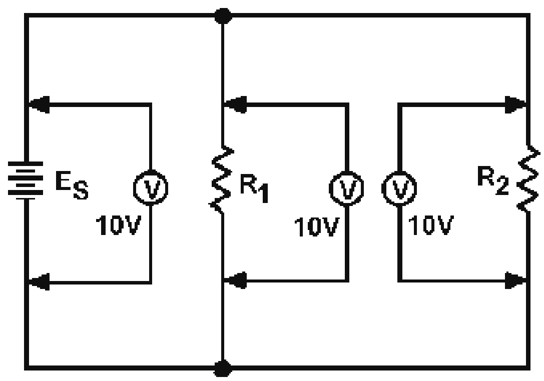


Figure 3-38.—Voltage comparison in a parallel circuit.

Example: Assume that the current through a resistor of a parallel circuit is known to be 4.5 milliamperes (4.5 mA) and the value of the resistor is 30,000 ohms (30 kΩ). Determine the source voltage. The circuit is shown in figure 3-39.

Given:

$$R_2 = 30{,}000 \text{ ohms } (30\text{k}\Omega)$$
$$I_{R2} = 4.5 \text{ milliamps } (4.5\text{mA or } .0045 \text{ amps})$$

Solution:

$$E = IR$$
$$E_{R2} = .0045 \text{ amp} \times 30{,}000 \text{ ohms}$$
$$E_{R2} = 135 \text{ volts}$$

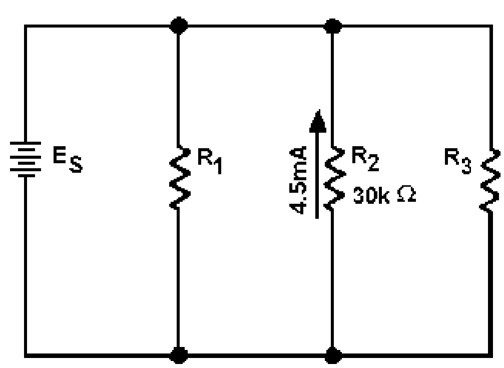


Figure 3-39.—Example problem parallel circuit.

Since the source voltage is equal to the voltage of a branch:

$$E_S = E_{R2}$$
$$E_S = 135 \text{ volts}$$

To simplify the math operation, the values can be expressed in powers of ten as follows:

$$30{,}000 \text{ ohms} = 30 \times 10^3 \text{ ohms}$$
$$4.5\text{mA} = 4.5 \times 10^{-3} \text{ amps}$$
$$E_{R2} = (4.5 \times 10^{-3}) \text{ amps} \times (30 \times 10^3) \text{ ohms}$$
$$E_{R2} = (4.5 \times 30 \times 10^{-3} \times 10^3) \text{ volts}$$
$$(10^{-3} \times 10^3 = 10^{-3+3} = 10^0 = 1)$$
$$E_{R2} = (4.5 \times 30 \times 1) \text{ volts}$$
$$E_{R2} = 135 \text{ volts}$$
$$E_S = E_{R2}$$
$$E_S = 135 \text{ volts}$$

If you are not familiar with the use of the powers of 10 or would like to brush up on it, Mathematics, Vol. 1, NAVEDTRA 10069-C, will be of great help to you.

Q33. What would the source voltage (E_S) in figure 3-39 be if the current through R_2 were 2 milliamps?

Current in a Parallel Circuit

Ohm's law states that the current in a circuit is inversely proportional to the circuit resistance. This fact is true in both series and parallel circuits.

There is a single path for current in a series circuit. The amount of current is determined by the total resistance of the circuit and the applied voltage. <u>In a parallel circuit the source current divides among the available paths.</u>

The behavior of current in parallel circuits will be shown by a series of illustrations using example circuits with different values of resistance for a given value of applied voltage.

Part (A) of figure 3-40 shows a basic series circuit. Here, the total current must pass through the single resistor. The amount of current can be determined.

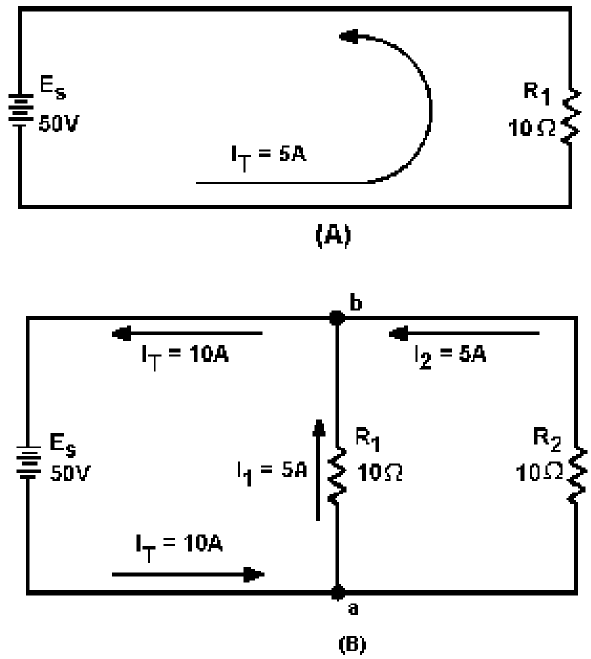


Figure 3-40.—Analysis of current in parallel circuit.

Given:

$$E_s = 50 \text{ volts}$$
$$R_1 = 10 \text{ ohms}$$

Solution:

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

$$I_T = \frac{E_s}{R_1}$$

$$I_T = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_T = 5 \text{ amps}$$

Part (B) of figure 3-40 shows the same resistor (R_1) with a second resistor (R_2) of equal value connected in parallel across the voltage source. When Ohm's law is applied, the current flow through each resistor is found to be the same as the current through the single resistor in part (A).

Given:

$$E_S = 50 \text{ volts}$$
$$R_1 = 10 \text{ ohms}$$
$$R_2 = 10 \text{ ohms}$$

Solution:

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

$$E_S = E_{R1} = E_{R2}$$

$$I_{R1} = \frac{E_{R1}}{R_1}$$

$$I_{R1} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R1} = 5 \text{ amps}$$

$$I_{R2} = \frac{E_{R2}}{R_2}$$

$$I_{R2} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R2} = 5 \text{ amps}$$

It is apparent that if there is 5 amperes of current through each of the two resistors, there must be a TOTAL CURRENT of 10 amperes drawn from the source.

The total current of 10 amperes, as illustrated in figure 3-40(B), leaves the negative terminal of the battery and flows to point a. Since point a is a connecting point for the two resistors, it is called a JUNCTION. At junction a, the total current divides into two currents of 5 amperes each. These two currents flow through their respective resistors and rejoin at junction b. The total current then flows from junction b back to the positive terminal of the source. The source supplies a total current of 10 amperes and each of the two equal resistors carries one-half the total current.

Each individual current path in the circuit of figure 3-40(B) is referred to as a BRANCH. Each branch carries a current that is a portion of the total current. Two or more branches form a NETWORK.

From the previous explanation, the characteristics of current in a parallel circuit can be expressed in terms of the following general equation:

$$I_T = I_1 + I_2 + \ldots I_n$$

Compare part (A) of figure 3-41 with part (B) of the circuit in figure 3-40. Notice that doubling the value of the second branch resistor (R_2) has no effect on the current in the first branch (I_{R1}), but does reduce the second branch current (I_{R2}) to one-half its original value. The total circuit current drops to a value equal to the sum of the branch currents. These facts are verified by the following equations.

Given:

$$E_S = 50 \text{ volts}$$
$$R_1 = 10 \text{ ohms}$$
$$R_2 = 20 \text{ ohms}$$

Solution:

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

$$E_S = E_{R1} = E_{R2}$$

$$I = \frac{E_{R1}}{R_1}$$

$$I = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R1} = 5 \text{ amps}$$

$$I_{R2} = \frac{E_{R2}}{R_2}$$

$$I_{R2} = \frac{50 \text{ volts}}{20 \text{ ohms}}$$

$$I_{R2} = 2.5 \text{ amps}$$

$$I_T = I_{R1} + I_{R2}$$

$$I_T = 5 \text{ amps} + 2.5 \text{ amps}$$

$$I_T = 7.5 \text{ amps}$$

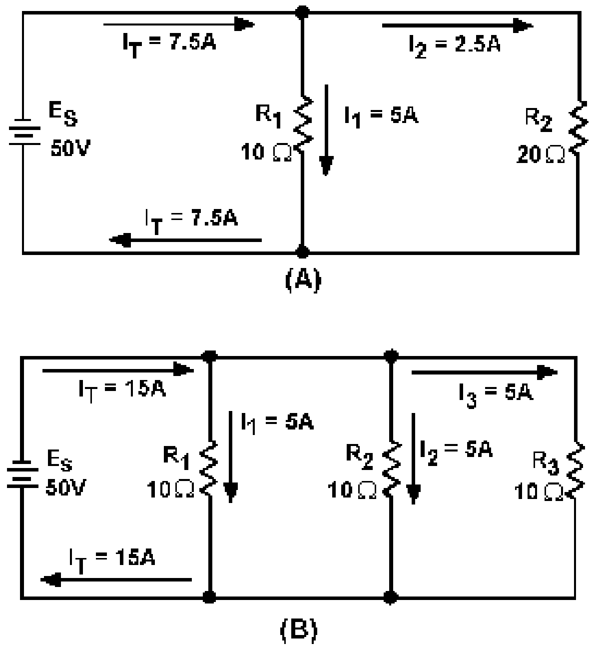


Figure 3-41.—Current behavior in parallel circuits.

The amount of current flow in the branch circuits and the total current in the circuit shown in figure 3-41(B) are determined by the following computations.

Given:

$$E_s = 50 \text{ volts}$$
$$R_1 = 10 \text{ ohms}$$
$$R_2 = 10 \text{ ohms}$$
$$R_3 = 10 \text{ ohms}$$

Solution:

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

$$E_S = E_{R1} = E_{R2} = E_{R3}$$

$$I_{R1} = \frac{E_{R1}}{R_1}$$

$$I_{R1} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R1} = 5 \text{ amps}$$

$$I_{R2} = \frac{E_{R2}}{R_2}$$

$$I_{R2} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R2} = 5 \text{ amps}$$

$$I_{R3} = \frac{E_{R3}}{R_3}$$

$$I_{R3} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R3} = 5 \text{ amps}$$

$$I_T = I_{R1} + I_{R2} + I_{R3}$$

$$I_T = 5 \text{ amps} + 5 \text{ amps} + 5 \text{ amps}$$

$$I_T = 15 \text{ amps}$$

Notice that the sum of the ohmic values in each circuit shown in figure 3-41 is equal (30 ohms), and that the applied voltage is the same (50 volts). However, the total current in 3-41(B) (15 amps) is twice the amount in 3-41(A) (7.5 amps). It is apparent, therefore, that the manner in which resistors are connected in a circuit, as well as their actual ohmic values, affect the total current.

The division of current in a parallel network follows a definite pattern. This pattern is described by KIRCHHOFF'S CURRENT LAW which states:

"The algebraic sum of the currents entering and leaving any junction of conductors is equal to zero."

This law can be stated mathematically as:

$$I_a + l_b + \ldots I_n + 0$$

where: I_a, I_b, etc., are the currents entering and leaving the junction. Currents ENTERING the junction are considered to be POSITIVE and currents LEAVING the junction are considered to be NEGATIVE. When solving a problem using Kirchhoff's current law, the currents must be placed into the equation WITH THE PROPER POLARITY SIGNS ATTACHED.

Example: Solve for the value of I_3 in figure 3-42.

Given:

$$I_1 = 10 \text{ amps}$$
$$I_2 = 3 \text{ amps}$$
$$I_4 = 5 \text{ amps}$$

$$I_a + I_b + \ldots I_n = 0$$

Solution:

$$I_a + l_b + \ldots I_a + 0$$

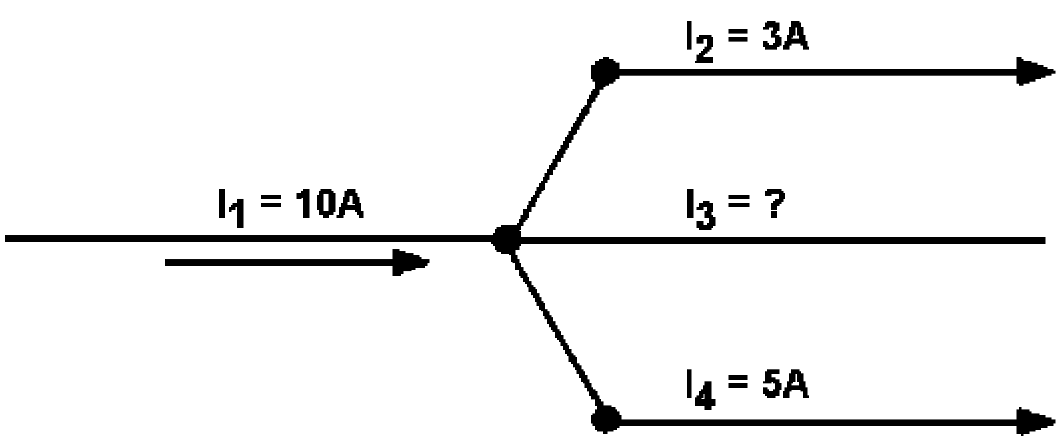


Figure 3-42.—Circuit for example problem.

The currents are placed into the equation with the proper signs.

$$I_1 + I_2 + I_3 + I_4 = 0$$
$$10 \text{ amps} + (-3 \text{ amps}) + I_3 + (-5 \text{ amps}) = 0$$
$$I_3 + 2 \text{ amps} = 0$$
$$I_3 = -2 \text{ amps}$$

I_3 has a value of 2 amperes, and the negative sign shows it to be a current LEAVING the junction.

Example. Using figure 3-43, solve for the magnitude and direction of I_3.

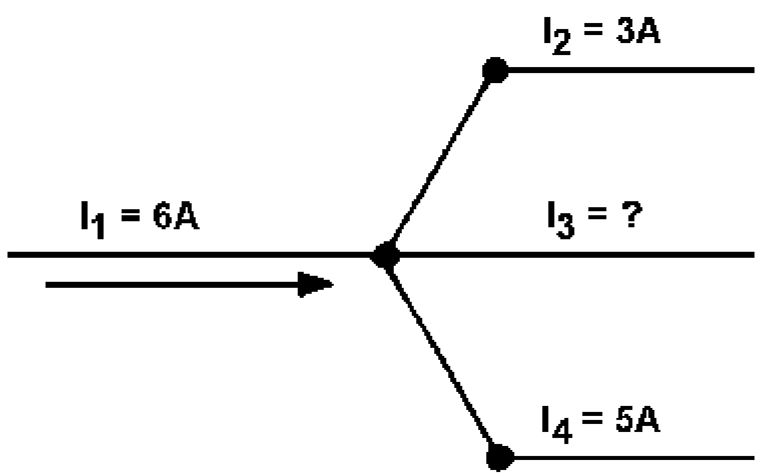


Figure 3-43.—Circuit for example problem.

Given:

$$I_1 = 6 \text{ amps}$$
$$I_2 = 3 \text{ amps}$$
$$I_4 = 5 \text{ amps}$$

Solution:

$$I_a + I_b + \ldots I_n = 0$$

$$I_1 + I_2 + I_3 + I_4 = 0$$

$$6 \text{ amps} + (-3 \text{ amps}) + I_3 + (-5 \text{ amps}) = 0$$

$$I_3 + (-2 \text{ amps}) = 0$$

$$I_3 = -2 \text{ amps}$$

I_3 is 2 amperes and its positive sign shows it to be a current entering the junction.

Q34. There is a relationship between total current and current through the individual components in a circuit. What is this relationship in a series circuit and a parallel circuit?

Q35. In applying Kirchhoff's current law, what does the polarity of the current indicate?

Resistance in a Parallel Circuit

In the example diagram, figure 3-44, there are two resistors connected in parallel across a 5-volt battery. Each has a resistance value of 10 ohms. A complete circuit consisting of two parallel paths is formed and current flows as shown.

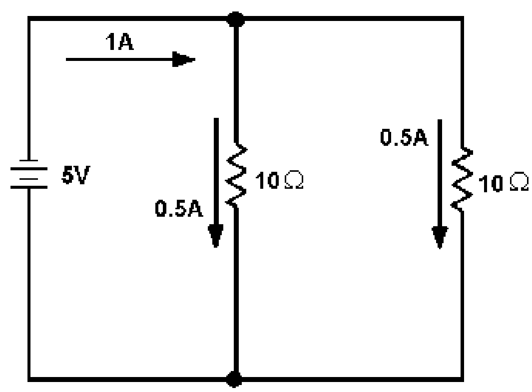


Figure 3-44.—Two equal resistors connected in parallel.

Computing the individual currents shows that there is one-half of an ampere of current through each resistance. The total current flowing from the battery to the junction of the resistors, and returning from the resistors to the battery, is equal to 1 ampere.

The total resistance of the circuit can be calculated by using the values of total voltage (E_T) and total current (I_T).

NOTE: From this point on the abbreviations and symbology for electrical quantities will be used in example problems.

Given:

$$E_T = 5\ V$$
$$I_T = 1\ A$$

Solution:

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

$$R_T = \frac{E_T}{I_T}$$

$$R_T = \frac{5\ V}{1\ A}$$

$$R_T = 5\ \Omega$$

This computation shows the total resistance to be 5 ohms; one-half the value of either of the two resistors.

Since the total resistance of a parallel circuit is smaller than any of the individual resistors, total resistance of a parallel circuit is not the sum of the individual resistor values as was the case in a series circuit. The total resistance of resistors in parallel is also referred to as EQUIVALENT RESISTANCE (R_{eq}). The terms total resistance and equivalent resistance are used interchangeably.

There are several methods used to determine the equivalent resistance of parallel circuits. The best method for a given circuit depends on the number and value of the resistors. For the circuit described above, where all resistors have the same value, the following simple equation is used:

$$R_{eq} = \frac{R}{N}$$

R_{eq} = equivalent parallel resistance

R = ohmic value of one resistor

N = number of resistors

This equation is valid for any number of parallel resistors of EQUAL VALUE.

Example: Four 40-ohm resistors are connected in parallel. What is their equivalent resistance?

Given:

$$R_1 + R_2 + R_3 + R_4$$
$$R_1 = 40\ \Omega$$

Solution:

$$R_{eq} = \frac{R}{N}$$

$$R_{eq} = \frac{40\Omega}{4}$$

$$R_{eq} = 10\ \Omega$$

Figure 3-45 shows two resistors of unequal value in parallel. Since the total current is shown, the equivalent resistance can be calculated.

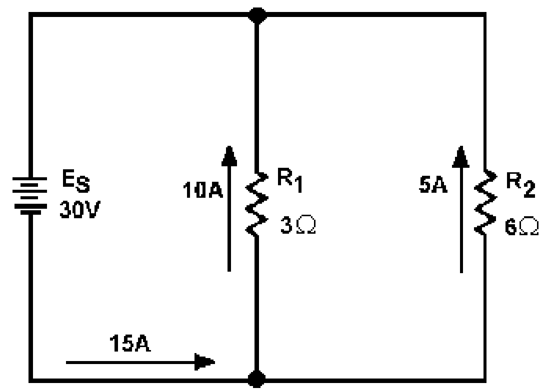


Figure 3-45.—Example circuit with unequal parallel resistors.

Given:

$$E_S = 30\ V$$
$$I_T = 15\ A$$

Solution:

$$R_{eq} = \frac{E_S}{I_T}$$

$$R_{eq} = \frac{30\ V}{15\ A}$$

$$R_{eq} = 2\ \Omega$$

The equivalent resistance of the circuit shown in figure 3-45 is smaller than either of the two resistors (R_1, R_2). An important point to remember is that <u>the equivalent resistance of a parallel circuit is always less than the resistance of any branch</u>.

Equivalent resistance can be found if you know the individual resistance values and the source voltage. By calculating each branch current, adding the branch currents to calculate total current, and dividing the source voltage by the total current, the total can be found. This method, while effective, is somewhat lengthy. A quicker method of finding equivalent resistance is to use the general formula for resistors in parallel:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$$

If you apply the general formula to the circuit shown in figure 3-45 you will get the same value for equivalent resistance (2Ω) as was obtained in the previous calculation that used source voltage and total current.

Given:

$$R_1 = 3\Omega$$
$$R_2 = 6\Omega$$

Solution:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$\frac{1}{R_{eq}} = \frac{1}{3\Omega} + \frac{1}{6\Omega}$$

Convert the fractions to a common denominator.

$$\frac{1}{R_{eq}} = \frac{2}{6\Omega} + \frac{1}{6\Omega}$$
$$\frac{1}{R_{eq}} = \frac{3}{6\Omega}$$
$$\frac{1}{R_{eq}} = \frac{1}{2\Omega}$$

Since both sides are reciprocals (divided into one), disregard the reciprocal function.

$$R_{eq} = 2\Omega$$

The formula you were given for equal resistors in parallel

$$\left(R_{eq} = \frac{R}{N} \right)$$

is a simplification of the general formula for resistors in parallel

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$$

There are other simplifications of the general formula for resistors in parallel which can be used to calculate the total or equivalent resistance in a parallel circuit.

RECIPROCAL METHOD.—This method is based upon taking the reciprocal of each side of the equation. This presents the general formula for resistors in parallel as:

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots \frac{1}{R_n}}$$

This formula is used to solve for the equivalent resistance of a number of unequal parallel resistors. You must find the lowest common denominator in solving these problems. If you are a little hazy on finding the lowest common denominator, brush up on it in *Mathematics Volume 1*, NAVEDTRA 10069 (Series).

Example: Three resistors are connected in parallel as shown in figure 3-46. The resistor values are: R_1 = 20 ohms, R_2 = 30 ohms, R_3 = 40 ohms. What is the equivalent resistance? (Use the reciprocal method.)

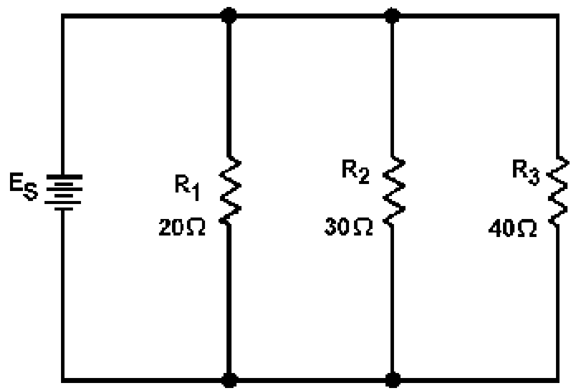


Figure 3-46.—Example parallel circuit with unequal branch resistors.

Given:

$$R_1 = 20\Omega$$
$$R_2 = 30\Omega$$
$$R_3 = 40\Omega$$

Solution:

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R3}}$$

$$R_{eq} = \frac{1}{\frac{1}{20\Omega} + \frac{1}{30\Omega} + \frac{1}{40\Omega}}$$

$$R_{eq} = \frac{1}{\frac{6}{120\Omega} + \frac{4}{120\Omega} + \frac{3}{120\Omega}}$$

$$R_{eq} = \frac{1}{\frac{13}{120}\Omega}$$

$$R_{eq} = \frac{120}{13}\Omega$$

$$R_{eq} = 9.23\Omega$$

PRODUCT OVER THE SUM METHOD.—A convenient method for finding the equivalent, or total, resistance of two parallel resistors is by using the following formula.

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

This equation, called the product over the sum formula, is used so frequently it should be committed to memory.

Example: What is the equivalent resistance of a 20-ohm and a 30-ohm resistor connected in parallel, as in figure 3-47?

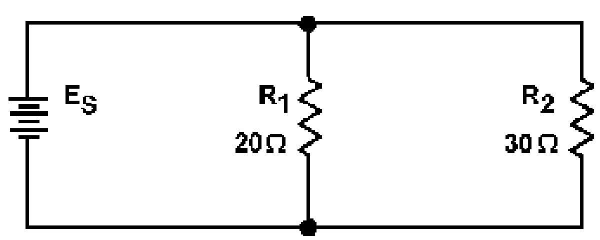


Figure 3-47.—Parallel circuit with two unequal resistors.

Given:

$$R_1 = 20\Omega$$
$$R_2 = 30\Omega$$

Solution:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$
$$R_{eq} = \frac{20\Omega \times 30\Omega}{20\Omega + 30\Omega}$$
$$R_{eq} = \frac{600}{50}\Omega$$
$$R_{eq} = 12\Omega$$

Q36. Four equal resistors are connected in parallel, each resistor has an ohmic value of 100 ohms, what is the equivalent resistance?

Q37. Three resistors connected in parallel have values of 12 kΩ, 20 kΩ, and 30 kΩ. What is the equivalent resistance?

Q38. Two resistors connected in parallel have values of 10 kΩ and 30 kΩ. What is the equivalent resistance?

Power in a Parallel Circuit

Power computations in a parallel circuit are essentially the same as those used for the series circuit. Since power dissipation in resistors consists of a heat loss, power dissipations are additive regardless of how the resistors are connected in the circuit. The total power is equal to the sum of the power dissipated by the individual resistors. Like the series circuit, the total power consumed by the parallel circuit is:

$$P_T = P_1 + P_2 + \ldots P_n$$

Example: Find the total power consumed by the circuit in figure 3-48.

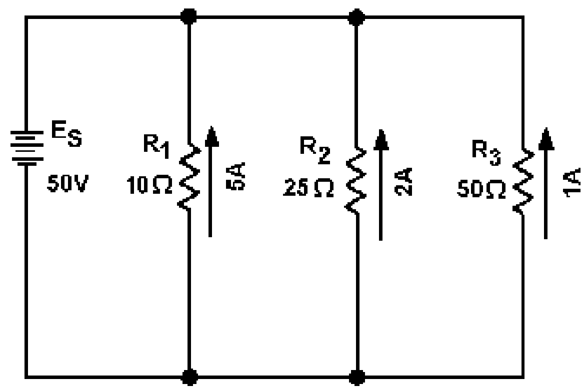


Figure 3-48.—Example parallel circuit.

Given:

$$R_1 = 10\ \Omega$$
$$I_{R1} = 5A$$

$$R_2 = 25\ \Omega$$
$$I_{R2} = 2A$$

$$R_3 = 50\ \Omega$$
$$I_{R3} = 1A$$

Solution:

$$P = I^2R$$
$$P_{R1} = (I_{R1})^2 \times R_1$$
$$P_{R1} = (5\ A)^2 \times 10\Omega$$
$$P_{R1} = 250W$$

$$P_{R2} = (I_{R2})^2 \times R_2$$
$$P_{R2} = (2\ A)^2 \times 25\Omega$$
$$P_{R2} = 100W$$

$$P_{R3} = (I_{R3})^2 \times R_3$$
$$P_{R3} = (1\ A)^2 \times 50\Omega$$
$$P_{R3} = 50W$$

$$P_T = P_{R1} + P_{R2} + P_{R3}$$
$$P_T = 250W + 100W + 50W$$
$$P_T = 400W$$

Since the total current and source voltage are known, the total power can also be computed by:

Given:

$$E_s = 50\ V$$
$$I_T = 8\ A$$

Solution:

$$P_T = E_S \times I_T$$
$$P_T = 50\ V \times 8\ A$$
$$P_T = 400W$$

Equivalent Circuits

In the study of electricity, it is often necessary to reduce a complex circuit into a simpler form. Any complex circuit consisting of resistances can be redrawn (reduced) to a basic equivalent circuit containing the voltage source and a single resistor representing total resistance. This process is called reduction to an EQUIVALENT CIRCUIT.

Figure 3-49 shows a parallel circuit with three resistors of equal value and the redrawn equivalent circuit. The parallel circuit shown in part A shows the original circuit. To create the equivalent circuit, you must first calculate the equivalent resistance.

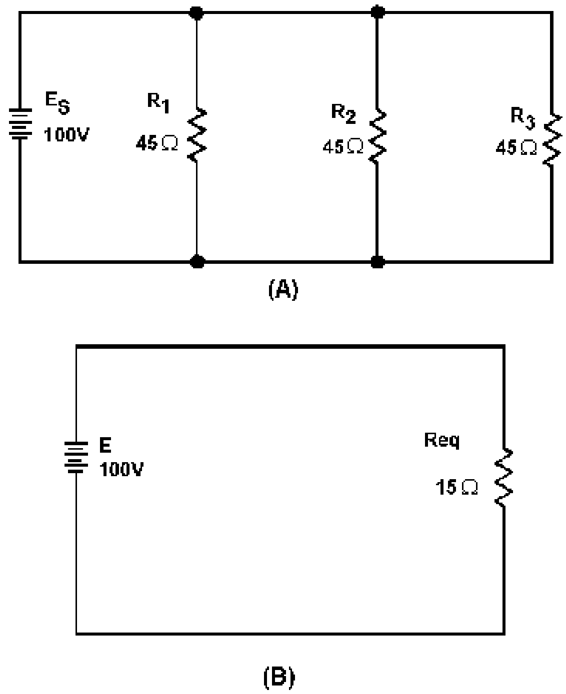


Figure 3-49.—Parallel circuit with equivalent circuit.

Given:

$$R_1 = 45\Omega$$
$$R_2 = 45\Omega$$
$$R3 = 45\Omega$$

Solution:

$$R_{eq} = \frac{R}{N}$$
$$R_{eq} = \frac{45\Omega}{3}$$
$$R_{eq} = 15\,\Omega$$

Once the equivalent resistance is known, a new circuit is drawn consisting of a single resistor (to represent the equivalent resistance) and the voltage source, as shown in part B.

Rules for Parallel DC Circuits

1. The same voltage exists across each branch of a parallel circuit and is equal to the source voltage.

2. The current through a branch of a parallel network is inversely proportional to the amount of resistance of the branch.

3. The total current of a parallel circuit is equal to the sum of the individual branch currents of the circuit.

4. The total resistance of a parallel circuit is found by the general formula:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots \frac{1}{R_n}$$

or one of the formulas derived from this general formula.

5. The total power consumed in a parallel circuit is equal to the sum of the power consumptions of the individual resistances.

SOLVING PARALLEL CIRCUIT PROBLEMS

Problems involving the determination of resistance, voltage, current, and power in a parallel circuit are solved as simply as in a series circuit. The procedure is the same — (1) draw the circuit diagram, (2) state the values given and the values to be found, (3) select the equations to be used in solving for the unknown quantities based upon the known quantities, and (4) substitute the known values in the equation you have selected and solve for the unknown value.

Example: A parallel circuit consists of five resistors. The value of each resistor is known and the current through R_1 is known. You are asked to calculate the value for total resistance, total power, total current, source voltage, the power used by each resistor, and the current through resistors R_2, R_3, R_4, and R_5.

Given:

$$R_1 = 20\Omega$$
$$R_2 = 30\Omega$$
$$R_3 = 18\Omega$$
$$R_4 = 18\Omega$$
$$R_5 = 18\Omega$$
$$I_{R1} = 9A$$

Find:

$$R_T, E_S, I_T, P_T, I_{R2}, I_{R3}, I_{R4},$$
$$I_{R5}, P_{R1}, P_{R2}, P_{R3}, P_{R4}, P_{R5}$$

This may appear to be a large amount of mathematical manipulation. However, if you use the step-by-step approach, the circuit will fall apart quite easily.

The first step in solving this problem is for you to draw the circuit and indicate the known values as shown in figure 3-50.

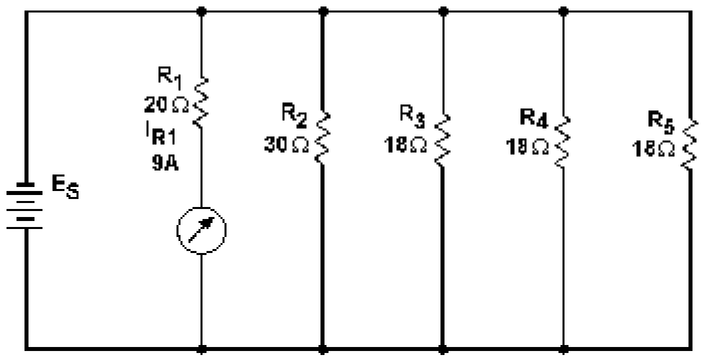


Figure 3-50.—Parallel circuit problem.

There are several ways to approach this problem. With the values you have been given, you could first solve for R_T, the power used by R_1, or the voltage across R_1, which you know is equal to the source voltage and the voltage across each of the other resistors. Solving for R_T or the power used by R_1 will not help in solving for the other unknown values.

Once the voltage across R_1 is known, this value will help you calculate other unknowns. Therefore the logical unknown to solve for is the source voltage (the voltage across R_1).

Given:

$$R_1 = 20\Omega$$
$$I_{R1} = 9A$$
$$E_{R1} = E_S$$

Solution:

$$E_S = R_1 \times I_{R1}$$
$$E_S = 9A \times 20\Omega$$
$$E_S = 180V$$

Now that source voltage is known, you can solve for current in each branch.

Given:

$$E_S = 180V$$
$$R_2 = 30\Omega$$
$$R_3 = 18\Omega$$
$$R_4 = 18\Omega$$
$$R_5 = 18\Omega$$

Solution:

$$I_{R2} = \frac{E_S}{R_2}$$

$$I_{R2} = \frac{180\text{ V}}{30\ \Omega}$$

$$I_{R2} = 6\text{ A}$$

$$I_{R3} = \frac{E_S}{R_3}$$

$$I_{R3} = \frac{180\text{ V}}{18\ \Omega}$$

$$I_{R3} = 10\text{ A}$$

Since $R_3 = R_4 = R_5$ and the voltage across each branch is the same:

$$I_{R4} = 10\text{A}$$
$$I_{R5} = 10\text{A}$$

Solving for total resistance.

Given:

$$R_1 = 20\Omega$$
$$R_2 = 30\Omega$$
$$R_3 = 18\Omega$$
$$R_4 = 18\Omega$$
$$R_5 = 18\Omega$$

Solution:

$$R_T = R_{eq}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$$

$$\frac{1}{R_T} = \frac{1}{20\Omega} + \frac{1}{30\Omega} + \frac{1}{18\Omega} + \frac{1}{18\Omega} + \frac{1}{18\Omega}$$

$$\frac{1}{R_T} = \frac{9 + 6 + 10 + 10 + 10\Omega}{180 \quad (\text{LCD})}$$

$$R_T = \frac{45\Omega}{180}$$

$$R_T = \frac{180}{45\Omega}$$

$$R_T = 4\Omega$$

An alternate method for solving for R_T can be used. By observation, you can see that R_3, R_4, and R_5 are of equal ohmic value. Therefore an equivalent resistor can be substituted for these three resistors in solving for total resistance.

Given:

$$R_3 = R_4 = R_5 = 18\Omega$$

Solution:

$$R_{eq1} = \frac{R}{N}$$

$$R_{eq1} = \frac{18\Omega}{3}$$

$$R_{eq1} = 6\Omega$$

The circuit can now be redrawn using a resistor labeled R_{eq1} in place of R_3, R_4, and R_5 as shown in figure 3-51.

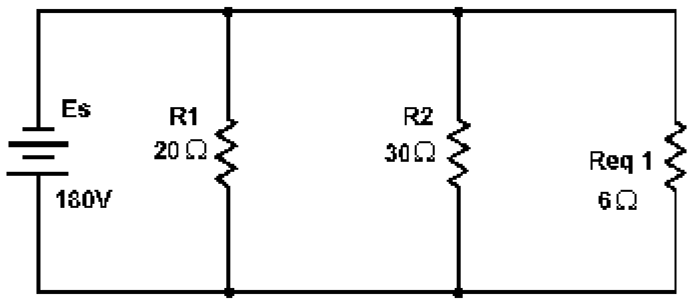


Figure 3-51.—First equivalent parallel circuit.

An equivalent resistor can be calculated and substituted for R_1 and R_2 by use of the product over the sum formula.

Given:

$$R_1 = 20\Omega$$
$$R_2 = 30\Omega$$

Solution:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$
$$R_{eq2} = \frac{20\Omega \times 30\Omega}{20\Omega + 30\Omega}$$
$$R_{eq2} = \frac{600}{50}\Omega$$
$$R_{eq2} = 12\Omega$$

The circuit is now redrawn again using a resistor labeled R_{eq2} in place of R_1 and R_2 as shown in figure 3-52.

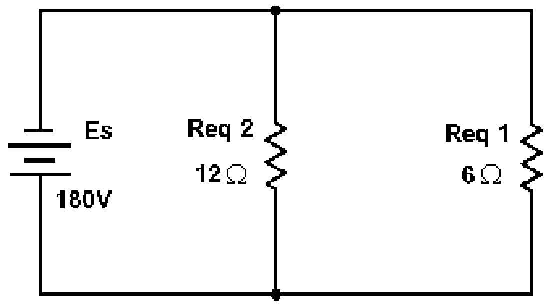


Figure 3-52.—Second equivalent parallel circuit.

You are now left with two resistors in parallel. The product over the sum method can now be used to solve for total resistance.

Given:

$$R_{eq1} = 6\Omega$$
$$R_{eq1} = 12\Omega$$
$$R_T = R_{eq}$$

Solution:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_T = \frac{R_{eq1} \times R_{eq2}}{R_{eq1} + R_{eq2}}$$

$$R_T = \frac{6\Omega \times 12\Omega}{6\Omega + 12\Omega}$$

$$R_T = \frac{72}{18}\Omega$$

$$R_T = 4\Omega$$

This agrees with the solution found by using the general formula for solving for resistors in parallel.

The circuit can now be redrawn as shown in figure 3-53 and total current can be calculated.

Figure 3-53.—Parallel circuit redrawn to final equivalent circuit.

Given:

$$E_S = 180V$$
$$R_T = 4\Omega$$

Solution:

$$I_T = \frac{E_S}{R_T}$$
$$I_T = \frac{180V}{4\Omega}$$
$$I_T = 45A$$

This solution can be checked by using the values already calculated for the branch currents.

Given:

$$I_{R1} = 9A$$
$$I_{R2} = 6A$$
$$I_{R3} = 10A$$
$$I_{R4} = 10A$$
$$I_{R5} = 10A$$

Solution:

$$I_T = I_{R1} + I_{R2} + \ldots I_{Rn}$$
$$I_T = 9A + 6A + 10A + 10A + 10A$$
$$I_T = 45A$$

Now that total current is known, the next logical step is to find total power.

Given:

$$E_S = 180V$$
$$I_T = 45A$$

Solution:

$$P = EI$$
$$P_T = E_S \times I_T$$
$$P_T = 180V \times 45A$$
$$P_T = 8100 \text{ watts} = 8.1\,kW$$

Solving for the power in each branch.

Given:

$$E_S = 180V$$
$$I_{R1} = 9A$$
$$I_{R2} = 6A$$
$$I_{R3} = 10A$$
$$I_{R4} = 10A$$
$$I_{R5} = 10A$$

Solution:

$$P = EI$$
$$P_{R1} = E_S \times I_{R1}$$
$$P_{R1} = 180V \times 9A$$
$$P_{R1} = 1620W$$

$$P_{R2} = E_S \times I_{R2}$$
$$P_{R2} = 180V \times 6A$$
$$P_{R2} = 1080W$$

$$P_{R3} = E_S \times I_{R3}$$
$$P_{R3} = 180V \times 10A$$
$$P_{R3} = 1800W$$

Since $I_{R3} = I_{R4} = I_{R5}$ then, $P_{R3} = P_{R4} = P_{R5}$ = 1800 W. The previous calculation for total power can now be checked.

Given:

$$P_{R1} = 1620W$$
$$P_{R2} = 1080W$$
$$P_{R3} = 1800W$$
$$P_{R4} = 1800W$$
$$P_{R5} = 1800W$$

Solution:

$$P_T = P_{R1} + P_{R2} + P_{R3} + P_{R4} + P_{R5}$$
$$P_T = 1620W + 1080W + 1800W + 1800W + 1800W$$
$$P_T = 8100W$$
$$P_T = 8.1kW$$

Q39. What term identifies a single resistor that represents total resistance of a complex circuit?

Q40. The total power in both series and parallel circuits is computed with the formula: $P_T = P_1 + P_2 + P_3 + \ldots P_n$. Why can this formula be used for both series and parallel circuits?

Q41. A circuit consists of three resistors connected in parallel across a voltage source. $R_l = 40\Omega$, $R_2 = 30\Omega$, $R_3 = 40\Omega$, and $P_{R3} = 360$ watts. Solve for R_T, E_S and I_{R2}. (Hint: Draw and label the circuit first.)

SERIES-PARALLEL DC CIRCUITS

In the preceding discussions, series and parallel dc circuits have been considered separately. The technician will encounter circuits consisting of both series and parallel elements. A circuit of this type is referred to as a COMBINATION CIRCUIT. Solving for the quantities and elements in a combination circuit is simply a matter of applying the laws and rules discussed up to this point.

SOLVING COMBINATION-CIRCUIT PROBLEMS

The basic technique used for solving dc combination-circuit problems is the use of equivalent circuits. To simplify a complex circuit to a simple circuit containing only one load, equivalent circuits are substituted (on paper) for the complex circuit they represent. To demonstrate the method used to solve combination circuit problems, the network shown in figure 3-54(A) will be used to calculate various circuit quantities, such as resistance, current, voltage, and power.

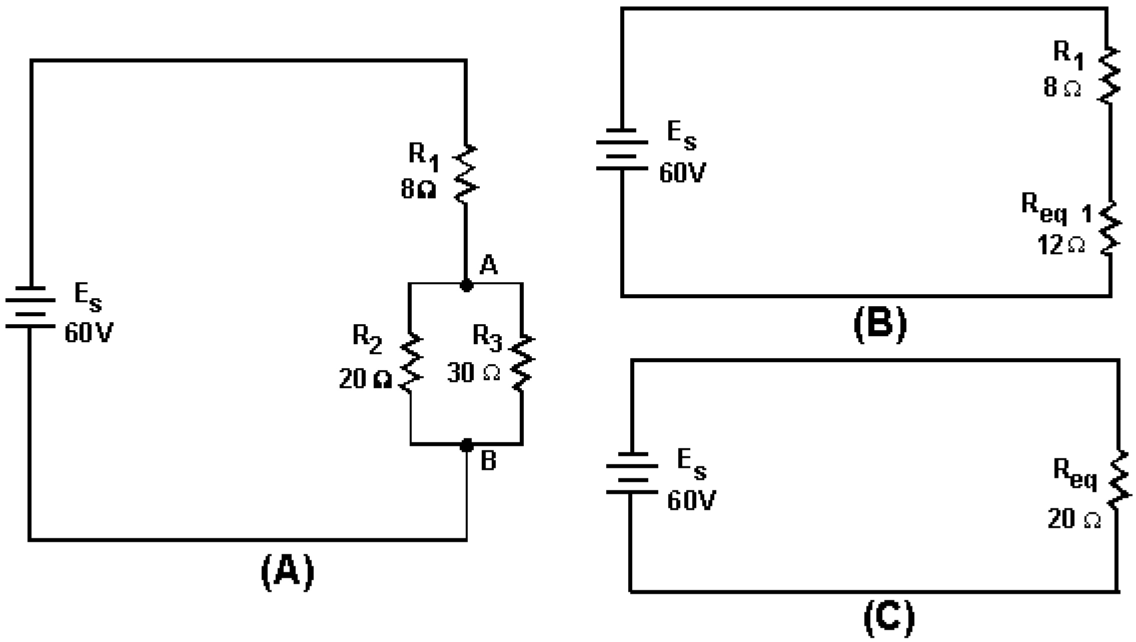


Figure 3-54.—Example combination circuit.

Examination of the circuit shows that the only quantity that can be computed with the given information is the equivalent resistance of R_2 and R_3.

Given:

$$R_2 = 20\Omega$$
$$R_3 = 30\Omega$$

Solution:

$$R_{eq1} = \frac{R_2 \times R_3}{R_2 + R_3} \quad \text{(Product over the sum)}$$

$$R_{eq1} = \frac{20\Omega \times 30\Omega}{20\Omega + 30\Omega}$$

$$R_{eq1} = \frac{600}{50}\Omega$$

$$R_{eq1} = 12\Omega$$

Now that the equivalent resistance for R_2 and R_3 has been calculated, the circuit can be redrawn as a series circuit as shown in figure 3-54(B).

The equivalent resistance of this circuit (total resistance) can now be calculated.

Given:

$$R_1 = 8\Omega \quad \text{(Resistors in series)}$$
$$R_{eq1} = 12\Omega$$

Solution:

$$R_{eq} = R_1 + R_{eq1}$$
$$R_{eq} = 8\Omega + 12\Omega$$
$$R_{eq} = 20\Omega$$
$$\text{or}$$
$$R_T = 20\Omega$$

The original circuit can be redrawn with a single resistor that represents the equivalent resistance of the entire circuit as shown in figure 3-54(C).

To find total current in the circuit:

Given:

$$E_S = 60V$$
$$R_T = 20\Omega$$

Solution:

$$I_T = \frac{E_S}{R_T}$$

$$I_T = \frac{60V}{20\Omega} \quad \text{(Ohm's Law)}$$

$$I_T = 3A$$

To find total power in the circuit:

Given:

$$E_S = 60V$$
$$I_T = 3A$$

Solution:

$$P_T = E_S \times I_T$$
$$P_T = 60V \times 3A$$
$$P_T = 180W$$

To find the voltage dropped across R_l, R_2, and R_3, refer to figure 3-54(B). R_{eq1} represents the parallel network of R_2 and R_3. Since the voltage across each branch of a parallel circuit is equal, the voltage across R_{eq1} (E_{eq1}) will be equal to the voltage across R_2 (E_{R2}) and also equal to the voltage across R_3 (E_{R3}).

Given:

$$I_T = 3A \quad \text{(Current through each part of a series circuit is equal to total current)}$$
$$R_1 = 8\Omega$$
$$R_{eq1} = 12\Omega$$

Solution:

$$E_{R1} = I_1 \times R_1$$
$$E_{R1} = 3A \times 8\Omega$$
$$E_{R1} = 24V$$
$$E_{R2} = E_{R3} = E_{eq1}$$
$$E_{eq1} = I_T \times R_{eq1}$$
$$E_{eq1} = 3A \times 12\Omega$$
$$E_{eq1} = 36V$$
$$E_{R2} = 36V$$
$$E_{R3} = 36V$$

To find power used by R_l:

Given:

$$E_{R1} = 24V$$
$$I_T = 3A$$

Solution:

$$P_{R1} = E_{R1} \times I_T$$
$$P_{R1} = 24V \times 3A$$
$$P_{R1} = 72W$$

To find the current through R_2 and R_3, refer to the original circuit, figure 3-54(A). You know E_{R2} and E_{R3} from previous calculation.

Given:

$$E_{R2} = 36V$$
$$E_{R3} = 36V$$
$$R_2 = 20\Omega$$
$$R_2 = 30\Omega$$

Solution:

$$I_{R2} = \frac{E_{R2}}{R_2} \quad \text{(Ohm's Law)}$$

$$I_{R2} = \frac{36V}{20\Omega}$$

$$I_{R2} = 1.8A$$

$$I_{R3} = \frac{E_{R3}}{R_3}$$

$$I_{R3} = \frac{36V}{30\Omega}$$

$$I_{R3} = 1.2A$$

To find power used by R_2 and R_3, using values from previous calculations:

Given:

$$E_{R2} = 36V$$
$$E_{R3} = 36V$$
$$I_{R2} = 1.8A$$
$$I_{R2} = 1.2A$$

Solution:

$$P_{R2} = E_{R2} \times I_{R2}$$
$$P_{R2} = 36V \times 1.8A$$
$$P_{R2} = 64.8W$$

$$P_{R3} = E_{R3} \times I_{R3}$$
$$P_{R3} = 36V \times 1.2A$$
$$P_{R3} = 43.2W$$

Now that you have solved for the unknown quantities in this circuit, you can apply what you have learned to any series, parallel, or combination circuit. It is important to remember to first look at the circuit and from observation make your determination of the type of circuit, what is known, and what you are looking for. A minute spent in this manner may save you many unnecessary calculations.

Having computed all the currents and voltages of figure 3-54, a complete description of the operation of the circuit can be made. The total current of 3 amps leaves the negative terminal of the battery and flows through the 8-ohm resistor (R_1). In so doing, a voltage drop of 24 volts occurs across resistor R_1. At point A, this 3-ampere current divides into two currents. Of the total current, 1.8 amps flows through the 20-ohm resistor. The remaining current of 1.2 amps flows from point A, down through the 30-ohm resistor to point B. This current produces a voltage drop of 36 volts across the 30-ohm resistor. (Notice that the voltage drops across the 20- and 30-ohm resistors are the same.) The two branch currents of 1.8 and 1.2 amps combine at junction B and the total current of 3 amps flows back to the source. The action of the circuit has been completely described with the exception of power consumed, which could be described using the values previously computed.

It should be pointed out that the combination circuit is not difficult to solve. The key to its solution lies in knowing the order in which the steps of the solution must be accomplished.

Practice Circuit Problem

Figure 3-55 is a typical combination circuit. To make sure you understand the techniques of solving for the unknown quantities, solve for E_{R1}.

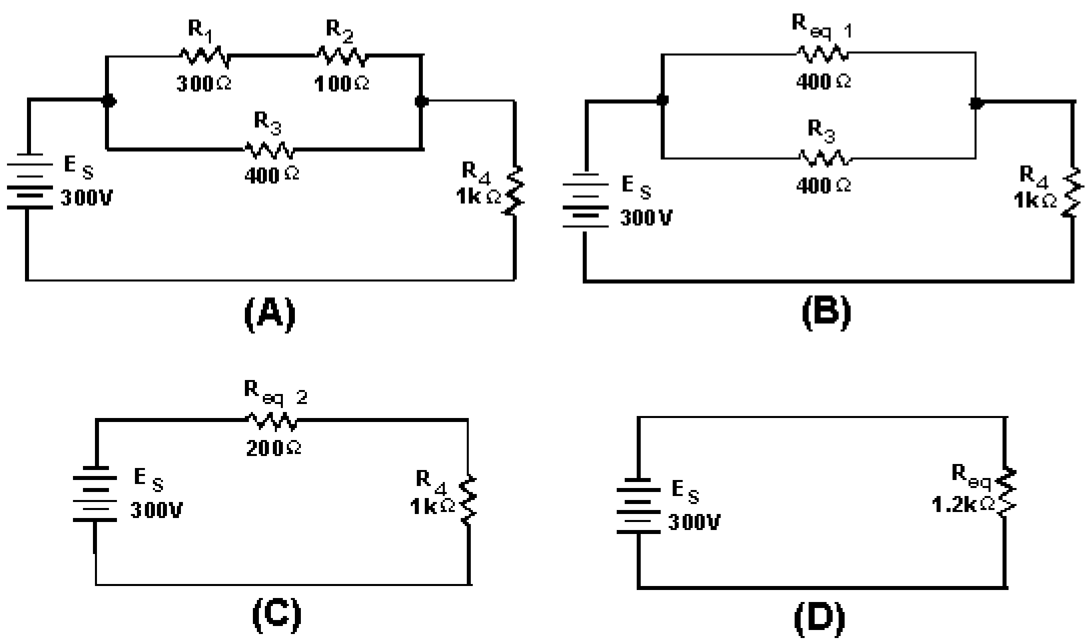


Figure 3-55.—Combination practice circuit.

It is not necessary to solve for all the values in the circuit to compute the voltage drop across resistor R_1 (E_{R1}). First look at the circuit and determine that the values given do not provide enough information to solve for E_{R1} directly.

If the current through R_1 (I_{R1}) is known, then E_{R1} can be computed by applying the formula:

$$E_{R1} = R_1 \times I_{R1}$$

The following steps will be used to solve the problem.

1. The total resistance (R_T) is calculated by the use of equivalent resistance.

Given:

$$R_1 = 300\Omega$$
$$R_2 = 100\Omega$$

Solution:

$$R_{eq1} = R_1 + R_2$$
$$R_{eq1} = 300\Omega + 100\Omega$$
$$R_{eq1} = 400\Omega$$

Redraw the circuit as shown in figure 3-55(B).

Given:

$$R_{eq1} = 400\Omega$$
$$R_3 = 400\Omega$$

Solution:

$$R_{eq2} = \frac{R}{N} \quad \text{(Equal resistors in parallel)}$$

$$R_{eq2} = \frac{400\Omega}{2}$$

$$R_{eq2} = 200\Omega$$

Solution:

$$R_{eq2} = \frac{R}{N}$$

$$R_{eq2} = \frac{400\Omega}{2}$$

$$R_{eq2} = 200\Omega$$

Redraw the circuit as shown in figure 3-55(C).

Given:

$$R_{eq2} = 200\Omega$$
$$R_4 = 1k\Omega$$

Solution:

$$R_{eq} = R_{eq2} + R_4$$
$$R_{eq} = 200\Omega + 1k\Omega$$
$$R_{eq} = 1.2k\Omega$$

2. The total current (I_T) is now computed.

Given:

$$E_S = 300V$$
$$R_{eq} = 1.2k\Omega$$

Solution:

$$I_T = \frac{E_S}{R_{eq}}$$

$$I_T = \frac{300V}{1.2k\Omega}$$

$$I_T = 250mA$$

3. Solve for the voltage dropped across R_{eq2}. This represents the voltage dropped across the network R_1, R_2, and R_3 in the original circuit.

Given:

$$R_{eq} = 200\Omega$$
$$I_T = 250mA$$

Solution:

$$E_{Req2} = R_{eq2} \times I_T$$
$$E_{Req2} = 200\Omega \times 250mA$$
$$E_{Req2} = 50V$$

4. Solve for the current through R_{eq1}. (R_{eq1} represents the network R_1 and R_2 in the original circuit.) Since the voltage across each branch of a parallel circuit is equal to the voltage across the equivalent resistor representing the circuit:

Given:

$$E_{Req2} = E_{Req1}$$
$$E_{Req1} = 50V$$
$$R_{eq1} = 400\Omega$$

Solution:

$$I_{Req1} = \frac{E_{Req1}}{R_{eq1}}$$

$$I_{Req1} = \frac{50V}{400\Omega}$$

$$I_{Req1} = 125mA$$

5. Solve for the voltage dropped across R_1 (the quantity you were asked to find). Since R_{eq1} represents the series network of R_1 and R_2 and total current flows through each resistor in a series circuit, I_{R1} must equal I_{Req1}.

Given:

$$I_{R1} = 125mA$$
$$R_1 = 300\Omega$$

Solution:

$$E_{R1} = I_{R1} \times R_1$$
$$E_{R1} = 125mA \times 300\Omega$$
$$E_{R1} = 37.5V$$

Q42. Refer to figure 3-55(A). If the following resistors were replaced with the values indicated: R_1 = 900Ω, R_3 = lkΩ, what is the total power in the circuit? What is E_{R2}?

REDRAWING CIRCUITS FOR CLARITY

You will notice that the schematic diagrams you have been working with have shown parallel circuits drawn as neat square figures, with each branch easily identified.

In actual practice the wired circuits and more complex schematics are rarely laid out in this simple form. For this reason, it is important for you to recognize that circuits can be drawn in a variety of ways, and to learn some of the techniques for redrawing them into their simplified form. When a circuit is redrawn for clarity or to its simplest form, the following steps are used.

1. Trace the current paths in the circuit.
2. Label the junctions in the circuit.
3. Recognize points which are at the same potential.

4. Visualize a rearrangement, "stretching" or "shrinking," of connecting wires.

5. Redraw the circuit into simpler form (through stages if necessary).

To redraw any circuit, start at the source, and trace the path of current flow through the circuit. At points where the current divides, called JUNCTIONS, parallel branches begin. These junctions are key points of reference in any circuit and should be labeled as you find them. The wires in circuit schematics are assumed to have NO RESISTANCE and there is NO VOLTAGE drop along any wire. This means that any unbroken wire is at the same voltage all along its length, until it is interrupted by a resistor, battery, or some other circuit component. In redrawing a circuit, a wire can be "stretched" or "shrunk" as much as you like without changing any electrical characteristic of the circuit.

Figure 3-56(A) is a schematic of a circuit that is not drawn in the box-like fashion used in previous illustrations. To redraw this circuit, start at the voltage source and trace the path for current to the junction marked (a). At this junction the current divides into three paths. If you were to stretch the wire to show the three current paths, the circuit would appear as shown in figure 3-56(B).

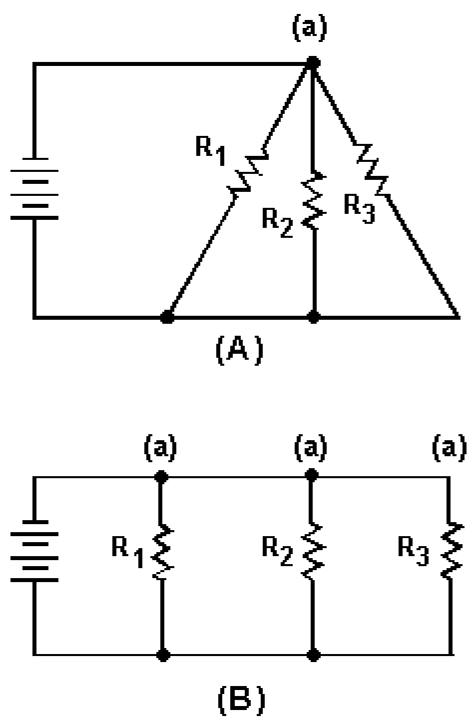


Figure 3-56.—Redrawing a simple parallel circuit.

While these circuits may appear to be different, the two drawings actually represent the same circuit. The drawing in figure 3-56(B) is the familiar box-like structure and may be easier to work with. Figure 3-57(A) is a schematic of a circuit shown in a box-like structure, but may be misleading. This circuit in reality is a series-parallel circuit that may be redrawn as shown in figure 3-57(B). The drawing in part (B) of the figure is a simpler representation of the original circuit and could be reduced to just two resistors in parallel.

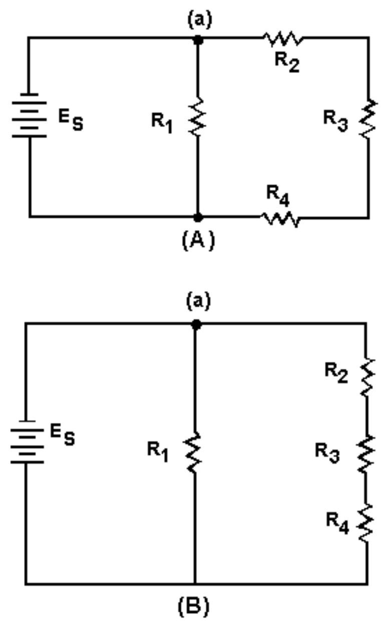


Figure 3-57.—Redrawing a simple series-parallel circuit.

Redrawing a Complex Circuit

Figure 3-58(A) shows a complex circuit that may be redrawn for clarification in the following steps.

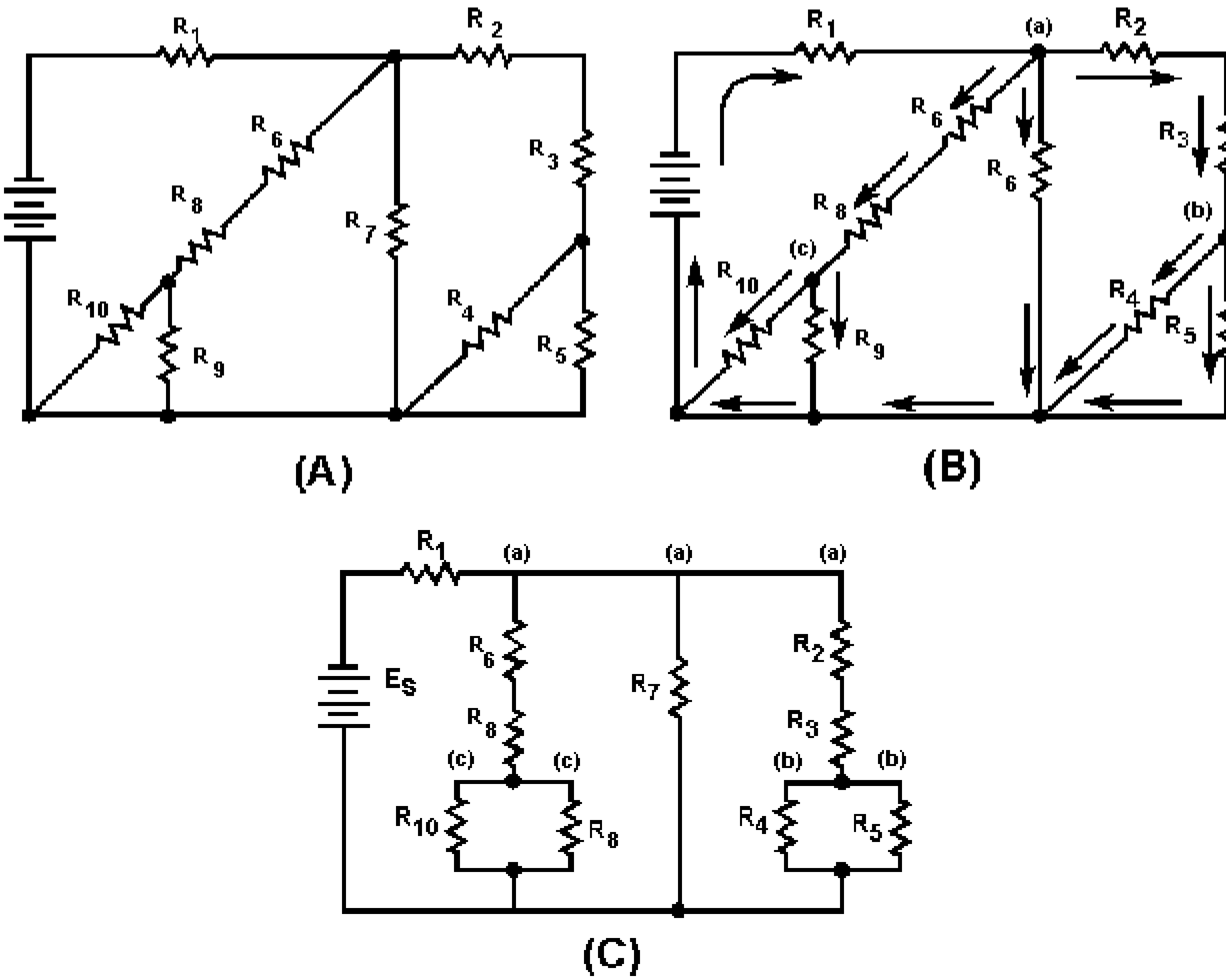


Figure 3-58.—Redrawing a complex circuit.

NOTE: As you redraw the circuit, draw it in simple box-like form. Each time you reach a junction, a new branch is created by stretching or shrinking the wires.

Start at the negative terminal of the voltage source. Current flows through R_1 to a junction and divides into three paths; label this junction (a). Follow one of the paths of current through R_2 and R_3 to a junction where the current divides into two more paths. This junction is labeled (b).

The current through one branch of this junction goes through R_5 and back to the source. (The most direct path.) Now that you have completed a path for current to the source, return to the last junction, (b). Follow current through the other branch from this junction. Current flows from junction (b) through R_4 to the source. All the paths from junction (b) have been traced. Only one path from junction (a) has been completed. You must now return to junction (a) to complete the other two paths. From junction (a) the current flows through R_7 back to the source. (There are no additional branches on this path.) Return to junction (a) to trace the third path from this junction. Current flows through R_6 and R_8 and comes to a junction. Label this junction (c). From junction (c) one path for current is through R_9 to the source. The other path for current from junction (c) is through R_{10} to the source. All the junctions in this circuit have now been labeled. The circuit and the junction can be redrawn as shown in figure 3-58(C). It is much easier to recognize the series and parallel paths in the redrawn circuit.

Q43. What is the total resistance of the circuit shown in figure 3-59? (Hint: Redraw the circuit to simplify and then use equivalent resistances to compute for R_T.)

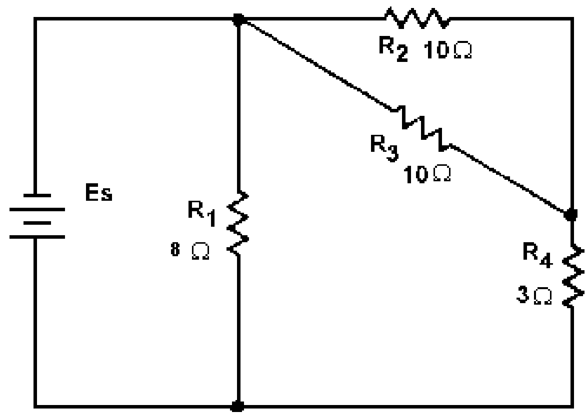


Figure 3-59.—Simplification circuit problem.

Q44. What is the total resistance of the circuit shown in figure 3-60?

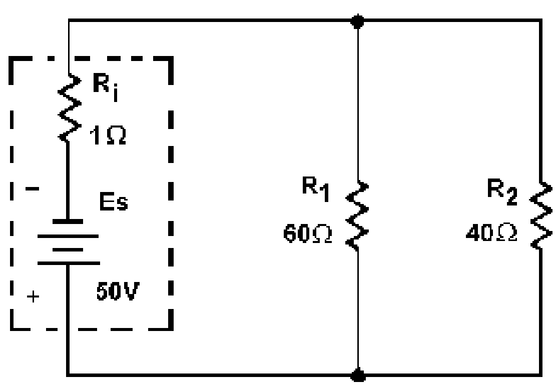


Figure 3-60.—Source resistance in a parallel circuit.

Q45. What effect does the internal resistance have on the rest of the circuit shown in figure 3-60?

EFFECTS OF OPEN AND SHORT CIRCUITS

Earlier in this chapter the terms open and short circuits were discussed. The following discussion deals with the effects on a circuit when an open or a short occurs.

The major difference between an open in a parallel circuit and an open in a series circuit is that in the parallel circuit the open would not necessarily disable the circuit. If the open condition occurs in a series portion of the circuit, there will be no current because there is no complete path for current flow. If, on the other hand, the open occurs in a parallel path, some current will still flow in the circuit. The parallel branch where the open occurs will be effectively disabled, total resistance of the circuit will INCREASE, and total current will DECREASE.

To clarify these points, figure 3-61 illustrates a series parallel circuit. First the effect of an open in the series portion of this circuit will be examined. Figure 3-61(A) shows the normal circuit, R_T = 40 ohms and I_T = 3 amps. In figure 3-61(B) an open is shown in the series portion of the circuit, there is no complete path for current and the resistance of the circuit is considered to be infinite.

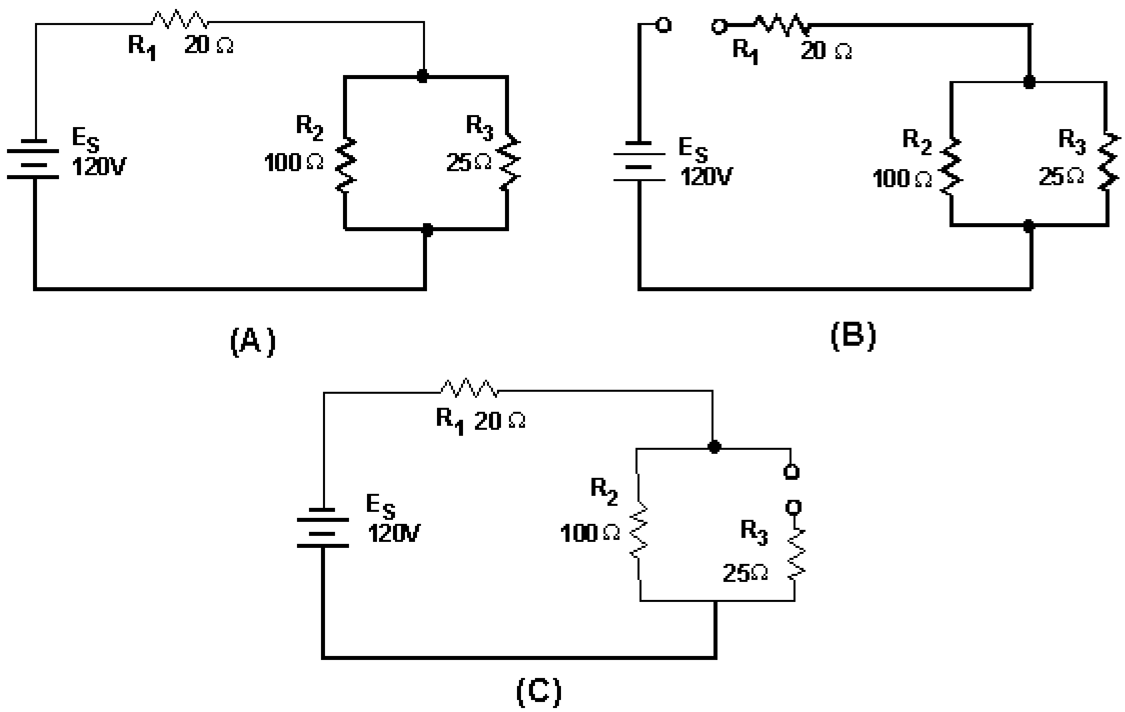


Figure 3-61.—Series-parallel circuit with opens.

In figure 3-61(C) an open is shown in the parallel branch of R_3. There is no path for current through R_3. In the circuit, current flows through R_1 and R_2 only. Since there is only one path for current flow, R_1 and R_2 are effectively in series.

Under these conditions $R_T = 120\Omega$ and I_T = 1 amp. As you can see, when an open occurs in a parallel branch, total circuit resistance increases and total circuit current decreases.

A short circuit in a parallel network has an effect similar to a short in a series circuit. In general, the short will cause an increase in current and the possibility of component damage regardless of the type of circuit involved. To illustrate this point, figure 3-62 shows a series-parallel network in which shorts are developed. In figure 3-62 (A) the normal circuit is shown. R_T = 40 ohms and I_T = 3 amps.

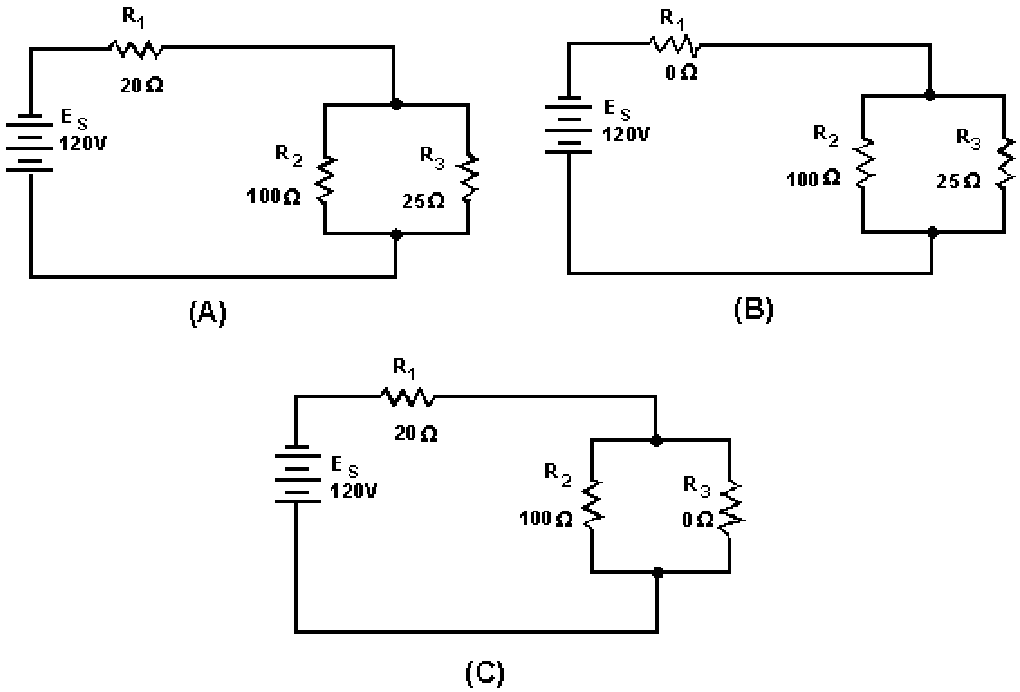


Figure 3-62.—Series-parallel circuit with shorts.

In figure 3-62 (B), R_1 has shorted. R_1 now has zero ohms of resistance. The total of the resistance of the circuit is now equal to the resistance of the parallel network of R_2 and R_3, or 20 ohms. Circuit current has increased to 6 amps. All of this current goes through the parallel network (R_2, R_3) and this increase in current would most likely damage the components.

In figure 3-62 (C), R_3 has shorted. With R_3 shorted there is a short circuit in parallel with R_2. The short circuit routes the current around R_2, effectively removing R_2 from the circuit. Total circuit resistance is now equal to the resistance of R_1, or 20 ohms.

As you know, R_2 and R_3 form a parallel network. Resistance of the network can be calculated as follows:

Given:

$$R_2 = 100\Omega$$
$$R_3 = 0\Omega$$

Solution:

$$R_{eq} = \frac{R_2 \times R_3}{R_2 + R_3}$$

$$R_{eq} = \frac{100\Omega \times 0\Omega}{100\Omega + 0\Omega}$$

$$R_{eq} = 0\Omega$$

The total circuit current with R_3 shorted is 6 amps. All of this current flows through R_1 and would most likely damage R_1. Notice that even though only one portion of the parallel network was shorted, the entire paralleled network was disabled.

Opens and shorts alike, if occurring in a circuit, result in an overall change in the equivalent resistance. This can cause undesirable effects in other parts of the circuit due to the corresponding change in the total current flow. A short usually causes components to fail in a circuit which is not properly fused or otherwise protected. The failure may take the form of a burned-out resistor, damaged source, or a fire in the circuit components and wiring.

Fuses and other circuit protection devices are installed in equipment circuits to prevent damage caused by increases in current. These circuit protection devices are designed to open if current increases to a predetermined value. Circuit protection devices are connected <u>in series</u> with the circuit or portion of the circuit that the device is protecting. When the circuit protection device opens, current flow ceases in the circuit.

A more thorough explanation of fuses and other circuit protection devices is presented in Module 3, *Introduction to Circuit Protection, Control, and Measurement*.

Q46. What is the effect on total resistance and total current in a circuit if an open occurs in (a) a parallel branch, and (b) in a series portion?

Q47. What is the effect on total resistance and total current in a circuit if a short occurs in (a) a parallel branch, and (b) in a series portion?

Q48. If one branch of a parallel network is shorted, what portion of circuit current flows through the remaining branches?

VOLTAGE DIVIDERS

Most electrical and electronics equipment use voltages of various levels throughout their circuitry.

One circuit may require a 90-volt supply, another a 150-volt supply, and still another a 180-volt supply. These voltage requirements could be supplied by three individual power sources. This method is expensive and requires a considerable amount of room. The most common method of supplying these voltages is to use a single voltage source and a VOLTAGE DIVIDER. Before voltage dividers are explained, a review of what was discussed earlier concerning voltage references may be of help.

As you know, some circuits are designed to supply both positive and negative voltages. Perhaps now you wonder if a negative voltage has any less potential than a positive voltage. The answer is that 100 volts is 100 volts. Whether it is negative or positive does not affect the feeling you get when you are shocked.

Voltage polarities are considered as being positive or negative in respect to a reference point, usually ground. Figure 3-63 will help to illustrate this point.

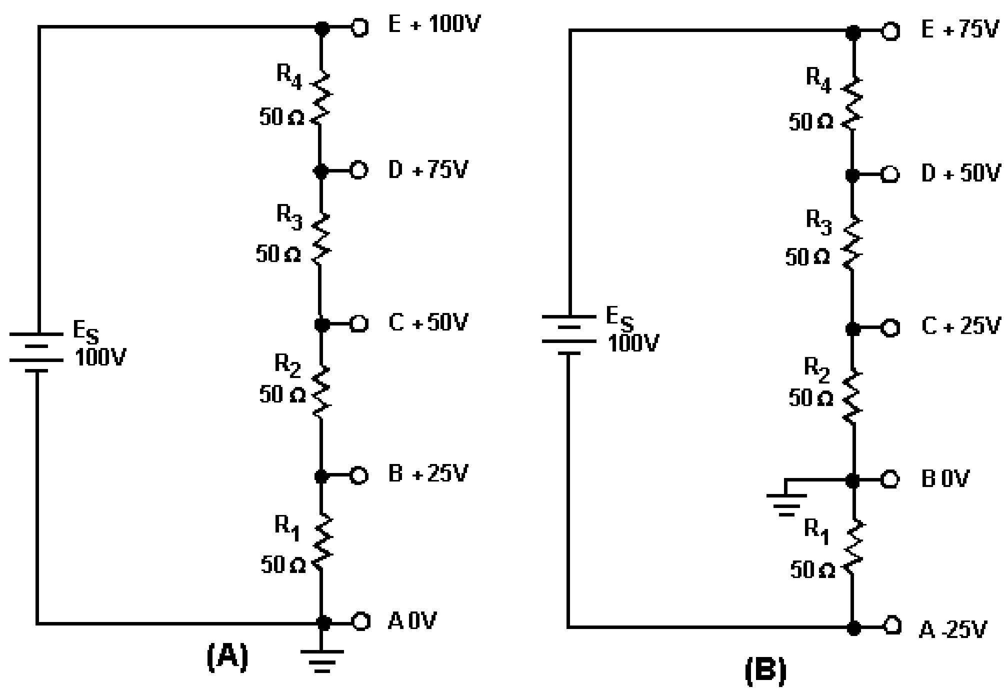


Figure 3-63.—Voltage polarities.

Figure 3-63(A) shows a series circuit with a voltage source of 100 volts and four 50-ohm resistors connected in series. The ground, or reference point, is connected to one end of resistor R_1. The current in this circuit determined by Ohm's law is .5 amp. Each resistor develops (drops) 25 volts. The five tap-off points indicated in the schematic are points at which the voltage can be measured. As indicated on the schematic, the voltage measured at each of the points from point A to point E starts at zero volts and becomes <u>more positive</u> in 25 volt steps to a value of positive 100 volts.

In figure 3-63(B), the ground, or reference point has been moved to point B. The current in the circuit is still .5 amp and each resistor still develops 25 volts. The total voltage developed in the circuit remains at 100 volts, but because the <u>reference point</u> has been changed, the voltage at point A is <u>negative</u> 25 volts. Point E, which was at positive 100 volts in figure 3-63(A), now has a voltage of positive 75 volts. As you can see the voltage at any point in the circuit is dependent on three factors; the current through the resistor, the ohmic value of the resistor, <u>and the reference point in the circuit.</u>

A typical voltage divider consists of two or more resistors connected in series across a source voltage (E_s). The source voltage must be as high or higher than any voltage developed by the voltage divider. As the source voltage is dropped in successive steps through the series resistors, any desired portion of the source voltage may be "tapped off" to supply individual voltage requirements. The values of the series resistors used in the voltage divider are determined by the voltage and current requirements of the loads.

Figure 3-64 is used to illustrate the development of a simple voltage divider. The requirement for this voltage divider is to provide a voltage of 25 volts and a current of 910 milliamps to the load from a source voltage of 100 volts. Figure 3-64(A) provides a circuit in which 25 volts is available at point B. If the load was connected between point B and ground, you might think that the load would be supplied with 25 volts. This is not true since the load connected between point B and ground forms a parallel network of the load and resistor R_1. (Remember that the value of resistance of a parallel network is always less than the value of the smallest resistor in the network.)

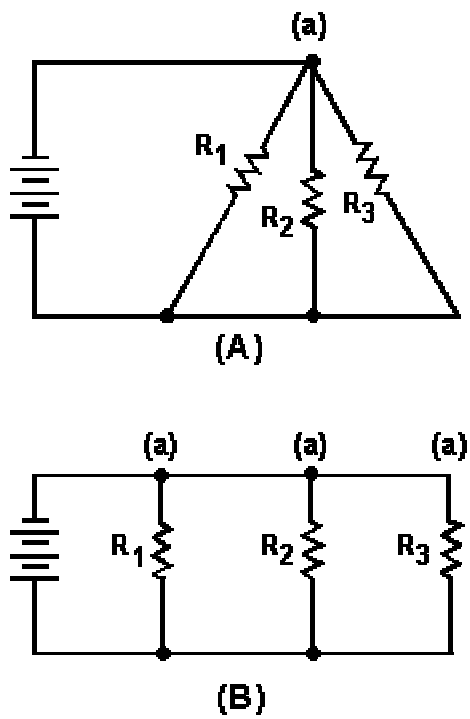


Figure 3-64.—Simple voltage divider.

Since the resistance of the network would now be less than 25 ohms, the voltage at point B would be less than 25 volts. This would not satisfy the requirement of the load.

To determine the size of resistor used in the voltage divider, a rule-of-thumb is used. The current in the divider resistor should equal approximately 10 percent of the load current. This current, which does not flow through any of the load devices, is called bleeder current.

Given this information, the voltage divider can be designed using the following steps.

1. Determine the load requirement and the available voltage source.

$$E_S = 100V$$
$$E_{load} = 25V$$
$$I_{load} = 910mA$$

2. Select bleeder current by applying the 10% rule-of-thumb.

$$I_{R1} = 10\% \times I_{load}$$
$$I_{R1} = .1 \times 910mA$$
$$I_{R1} = 91mA$$

3. Calculate bleeder resistance.

$$R_1 = \frac{E_{R1}}{I_{R1}}$$

$$R_1 = \frac{25V}{91mA}$$

$$R1 = 274.73\Omega$$

The value of R_1 may be rounded off to 275 ohms:

$$R_1 = 275\Omega$$

4. Calculate the total current (load plus bleeder).

$$I_T = I_{load} + I_{R1}$$
$$I_T = 910mA + 91mA$$
$$I_T = 1A \text{ (rounded off)}$$

5. Calculate the resistance of the other divider resistor(s).

$$E_{R2} = E_S - E_{R1}$$
$$E_{R2} = 100V - 25V$$
$$E_{R2} = 75V$$
$$R_2 = \frac{E_{R2}}{I_T}$$
$$R_2 = \frac{75V}{1A}$$
$$R_2 = 75\Omega$$

The voltage divider circuit can now be drawn as shown in figure 3-64(B).

Q49. What information must be known to determine the component values for a voltage divider?

Q50. If a voltage divider is required for a load that will use 450 mA of current, what should be the value of bleeder current?

Q51. If the load in question 50 requires a voltage of +90 V, what should be the value of the bleeder resistor?

Q52. If the source voltage for the voltage divider in question 50 supplies 150 volts, what is the total current through the voltage divider?

MULTIPLE-LOAD VOLTAGE DIVIDERS

A multiple-load voltage divider is shown in figure 3-65. An important point that was not emphasized before is that when using the 10% rule-of-thumb to calculate the bleeder current, you must take 10% of the total load current.

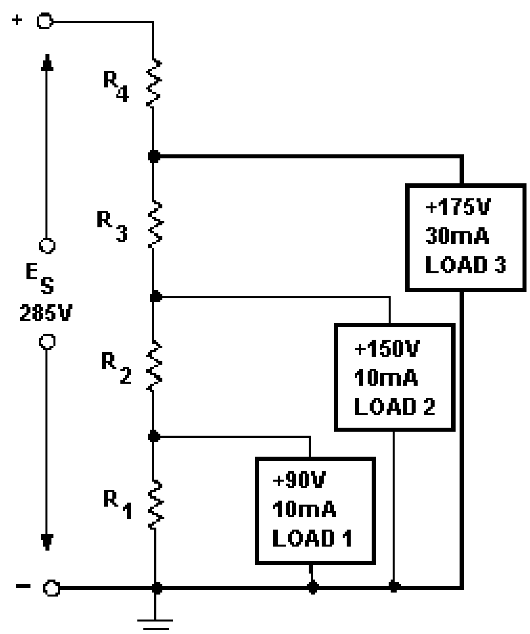


Figure 3-65.—Multiple-load voltage divider.

Given the information shown in figure 3-65, you can calculate the values for the resistors needed in the voltage-divider circuits. The same steps will be followed as in the previous voltage divider problem.

Given:

$$\text{Load 1:}\quad E = 90V$$
$$I = 10mA$$

$$\text{Load 2:}\quad E = 150V$$
$$I = 10mA$$

$$\text{Load 3:}\quad E = 175V$$
$$I = 30mA$$

$$E_S = 285V$$

The bleeder current should be 10% of the total load current.

Solution:

$$I_{R1} = 10\% \times I\,(\text{load total})$$
$$I_{R1} = 10\% \times (10mA + 10mA + 30mA)$$
$$I_{R1} = 5mA$$

Since the voltage across R_1 (E_{R1}) is equal to the voltage requirement for load 1, Ohm's law can be used to calculate the value for R_1.

Solution:

$$R_1 = \frac{E_{R1}}{I_{R1}}$$

$$R_1 = \frac{90V}{5mA}$$

$$R_1 = 18k\Omega$$

The current through R_2 (I_{R2}) is equal to the current through R_1 plus the current through load 1.

Solution:

$$I_{R2} = I_{R1} + I_{load1}$$
$$I_{R2} = 5mA + 10mA$$
$$I_{R2} = 15mA$$

The voltage across R_2 (E_{R2}) is equal to the difference between the voltage requirements of load 1 and load 2.

$$E_{R2} = E_{load2} - E_{load1}$$
$$E_{R2} = 150V - 90V$$
$$E_{R2} = 60V$$

Ohm's law can now be used to solve for the value of R_2.

Solution:

$$R_2 = \frac{E_{R2}}{I_{R2}}$$
$$R_2 = \frac{60V}{15mA}$$
$$R_2 = 4k\Omega$$

The current through R_3 (I_{R3}) is equal to the current through R_2 plus the current through load 2.

$$I_{R3} = I_{R2} + I_{load2}$$
$$I_{R3} = 15mA + 10mA$$
$$I_{R3} = 25mA$$

The voltage across R_3 (E_{R3}) equals the difference between the voltage requirement of load 3 and load 2.

$$E_{R3} = E_{load3} - E_{load2}$$
$$E_{R3} = 175V - 150V$$
$$E_{R3} = 25V$$

Ohm's law can now be used to solve for the value of R_3.

Solution:

$$R_3 = \frac{E_{R3}}{I_{R3}}$$
$$R_3 = \frac{25V}{25mA}$$
$$R_3 = 1k\Omega$$

The current through R_4 (I_{R4}) is equal to the current through R_3 plus the current through load 3. I_{R4} is equal to total circuit current (I_T).

$$I_{R4} = I_{R3} + I_{load3}$$
$$I_{R4} = 25mA + 30mA$$
$$I_{R4} = 55mA$$

The voltage across R_4 (E_{R4}) equals the difference between the source voltage and the voltage requirement of load 3.

$$E_{R4} = E_S - E_{load3}$$
$$E_{R4} = 285V - 175V$$
$$E_{R4} = 110V$$

Ohm's law can now be used to solve for the value of R_4.

Solution:

$$R_4 = \frac{E_{R4}}{I_{R4}}$$
$$R_4 = \frac{110V}{55mA}$$
$$R_4 = 2k\Omega$$

With the calculations just explained, the values of the resistors used in the voltage divider are as follows:

$$R_1 = 18k\Omega$$
$$R_2 = 4k\Omega$$
$$R_3 = 1k\Omega$$
$$R_4 = 2k\Omega$$

POWER IN THE VOLTAGE DIVIDER

Power in the voltage divider is an extremely important quantity. The power dissipated by the resistors in the voltage divider should be calculated to determine the power handling requirements of the resistors. Total power of the circuit is needed to determine the power requirement of the source.

The power for the circuit shown in figure 3-65 is calculated as follows:

Given:

$$E_{R1} = 90V$$
$$E_{R1} = 5mA$$

Solution:

$$P_{R1} = E_{R3} \times I_{R1}$$
$$P_{R1} = 90V \times 5mA$$
$$P_{R1} = .45W$$

The power in each resistor is calculated just as for R_1. When the calculations are performed, the following results are obtained:

$$P_{R2} = .9W$$
$$P_{R3} = .625W$$
$$P_{R4} = 6.05W$$

To calculate the power for load 1:

Given:

$$E_{load1} = 90V$$
$$I_{load1} = 10mA$$

Solution:

$$P_{load1} = E_{load1} \times I_{load1}$$
$$P_{load1} = 90V \times 10mA$$
$$P_{load1} = .9W$$

The power in each load is calculated just as for load 1. When the calculations are performed, the following results are obtained.

$$P_{load2} = 1.5W$$
$$P_{load3} = 5.25W$$

Total power is calculated by summing the power consumed by the loads and the power dissipated by the divider resistors. The total power in the circuit is 15.675 watts.

The power used by the loads and divider resistors is supplied by the source. This applies to all electrical circuits; power for all components is supplied by the source.

Since power is the product of voltage and current, the power supplied by the source is equal to the source voltage multiplied by the total circuit current (E_s x I_T).

In the circuit of figure 3-65, the total power can be calculated by:

Given:

$$E_S = 285V$$
$$I_T = 55mA\ (I_{R4})$$

Solution:

$$P_T = E_S \times I_T$$
$$P_T = 285V \times 55mA$$
$$P_T = 15.675W$$

VOLTAGE DIVIDER WITH POSITIVE AND NEGATIVE VOLTAGE REQUIREMENTS

In many cases the load for a voltage divider requires both positive and negative voltages. Positive and negative voltages can be supplied from a single source voltage by connecting the ground (reference point) between two of the divider resistors. The exact point in the circuit at which the reference point is placed depends upon the voltages required by the loads.

For example, a voltage divider can be designed to provide the voltage and current to three loads from a given source voltage.

Given:

$$\text{Load 1:}\quad E = -25V \qquad I = 300mA$$

$$\text{Load 2:}\quad E = +50V \qquad I = 50mA$$

$$\text{Load 3:}\quad E = +250V \qquad I = 100mA$$

$$E_S = 310V$$

The circuit is drawn as shown in figure 3-66. Notice the placement of the ground reference point. The values for resistors R_1, R_3, and R_4 are computed exactly as was done in the last example. I_{R1} is the bleeder current and can be calculated as follows:

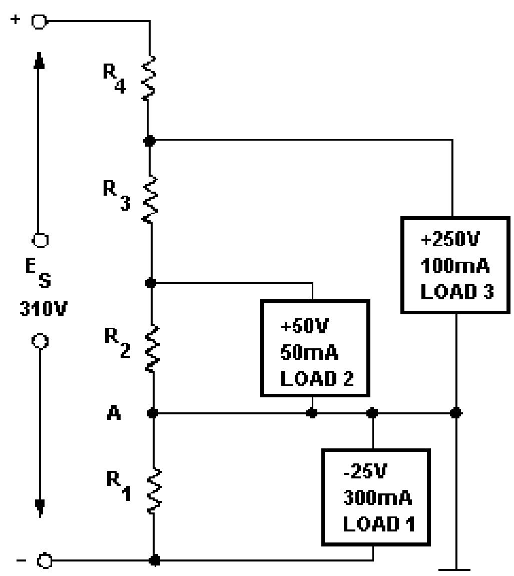


Figure 3-66.—Voltage divider providing both positive and negative voltages.

Solution:

$$I_{R1} = 10\% \times I\,(\text{load total})$$
$$I_{R1} = 10\% \times (300mA)$$
$$I_{R1} = 30mA$$

Calculate the value of R_1.

Solution:

$$R_1 = \frac{E_{R1}}{I_{R1}}$$
$$R_1 = \frac{25V}{45mA}$$
$$R_1 = 556\Omega$$

Calculate the current through R_2 using Kirchhoff's current law.

At point A:

$$I_{R1} + I_{load1} + I_{R2} + I_{load2} + I_{load3} = 0$$
$$45mA + 300mA + I_{R2} - 50mA - 100mA = 0$$
$$345mA + I_{R2} - 150mA = 0$$
$$195mA + I_{R2} = 0$$
$$I_{R2} = -195mA$$

(or 195mA leaving point A)

Since E_{R2} = E load 2, you can calculate the value of R_2.

Solution:

$$R_2 = \frac{E_{R2}}{I_{R2}}$$
$$R_2 = \frac{50V}{195mA}$$
$$R_2 = 256\Omega$$

Calculate the current through R_3.

$$I_{R3} = I_{R2} + I_{load2}$$
$$I_{R3} = 195mA + 50mA$$
$$I_{R3} = 245mA$$

The voltage across R_3 (E_{R3}) equals the difference between the voltage requirements of loads 3 and 2.

Solution:

$$E_{R3} = E_{load3} - E_{load2}$$
$$E_{R3} = 250V - 50V$$
$$E_{R3} = 200V$$

Calculate the value of R_3.

Solution:

$$R_3 = \frac{E_{R3}}{I_{R3}}$$
$$R_3 = \frac{200V}{245mA}$$
$$R_3 = 816\Omega$$

Calculate the current through R_4.

$$I_{R4} = I_{R3} + I_{load3}$$
$$I_{R4} = 245mA + 100mA$$
$$I_{R4} = 345mA$$

The voltage across E_{R4} equals the source voltage (E_s) minus the voltage requirement of load 3 and the voltage requirement of load 1. Remember Kirchhoff's voltage law which states that the sum of the voltage drops and emfs around any closed loop is equal to zero.

Solution:

$$E_{R4} = E_S - E_{load3} - E_{load1}$$
$$E_{R4} = 310V - 250V - 25v$$
$$E_{R4} = 35V$$

Calculate the value of R_4.

Solution:

$$R_4 = \frac{E_{R4}}{I_{R4}}$$

$$R_4 = \frac{35V}{345mA}$$

$$R_4 = 101.4\Omega$$

With the calculations just explained, the values of the resistors used in the voltage /divider are as follows:

$$R_1 = 556\Omega$$
$$R_2 = 256\Omega$$
$$R_3 = 816\Omega$$
$$R_4 = 101\Omega$$

From the information just calculated, any other circuit quantity, such as power, total current, or resistance of the load, could be calculated.

PRACTICAL APPLICATION OF VOLTAGE DIVIDERS

In actual practice the computed value of the bleeder resistor does not always come out to an even value. Since the rule-of-thumb for bleeder current is only an estimated value, the bleeder resistor can be of a value close to the computed value. (If the computed value of the resistance were 510 ohms, a 500-ohm resistor could be used.) Once the actual value of the bleeder resistor is selected, the bleeder current must be recomputed. <u>The voltage developed by the bleeder resistor must be equal to the voltage requirement of the load in parallel with the bleeder resistor</u>.

The value of the remaining resistors in the voltage divider is computed from the current through the remaining resistors and the voltage across them. These values <u>must be used</u> to provide the required voltage and current to the loads.

If the computed values for the divider resistors are not even values; series, parallel, or series-parallel networks can be used to provide the required resistance.

Example: A voltage divider is required to supply two loads from a 190.5 volts source. Load 1 requires +45 volts and 210 milliamps; load 2 requires +165 volts and 100 milliamps.

Calculate the bleeder current using the rule-of-thumb.

Given:

$$I_{load1} = 210mA$$
$$I_{load2} = 100mA$$

Solution:

$$I_{R1} = 10\% \times (210mA + 100mA)$$
$$I_{R1} = 31mA$$

Calculate the ohmic value of the bleeder resistor.

Given:

$$E_{R1} = 45V \ (E_{load1})$$
$$I_{R1} = 31mA$$

Solution:

$$R_1 = \frac{E_{R1}}{I_{R1}}$$
$$R_1 = \frac{45V}{31mA}$$
$$R_1 = 1451.6\Omega$$

Since it would be difficult to find a resistor of 1451.6 ohms, a practical choice for R_1 is 1500 ohms.

Calculate the actual bleeder current using the selected value for R_1.

Given:

$$E_{R1} = 45V$$
$$I_{R1} = 1.5k\Omega$$

Solution:

$$I_{R1} = \frac{E_{R1}}{R_1}$$

$$I_{R1} = \frac{45V}{1.5k\Omega}$$

$$I_{R1} = 30mA$$

Using this value for I_{R1}, calculate the resistance needed for the next divider resistor. The current (I_{R2}) is equal to the bleeder current plus the current used by load 1.

Given:

$$I_{R1} = 30mA$$
$$I_{load1} = 210mA$$

Solution:

$$I_{R2} = I_{R1} + I_{load1}$$
$$I_{R2} = 30mA + 210mA$$
$$I_{R4} = 240mA$$

The voltage across R_2 (E_{R2}) is equal to the difference between the voltage requirements of loads 2 and 1, or 120 volts.

Calculate the value of R_2.

Given:

$$E_{R2} = 120V$$
$$I_{R2} = 240mA$$

Solution:

$$R_2 = \frac{E_{R2}}{I_{R2}}$$

$$R_2 = \frac{120V}{240mA}$$

$$R_2 = 500\Omega$$

The value of the final divider resistor is calculated with I_{R3} (I_{R2} + I load 2) equal to 340 mA and E_{R3} (E_s - E load 2) equal to 25.5V.

Given:

$$E_{R3} = 25.5V$$
$$I_{R3} = 340mA$$

Solution:

$$R_3 = \frac{E_{R3}}{I_{R3}}$$

$$R_3 = \frac{25.5V}{340mA}$$

$$R_3 = 75\Omega$$

A 75-ohm resistor may not be easily obtainable, so a network of resistors equal to 75 ohms can be used in place of R_3.

Any combination of resistor values adding up to 75 ohms could be placed in series to develop the required network. For example, if you had two 37.5-ohm resistors, you could connect them in series to get a network of 75 ohms. One 50-ohm and one 25-ohm resistor or seven 10-ohm and one 5-ohm resistor could also be used.

A parallel network could be constructed from two 150-ohm resistors or three 225-ohm resistors. Either of these parallel networks would also be a network of 75 ohms.

The network used in this example will be a series-parallel network using three 50-ohm resistors.

With the information given, you should be able to draw this voltage divider network.

Once the values for the various divider resistors have been selected, you can compute the power used by each resistor using the methods previously explained. When the power used by each resistor is known, the wattage rating required of each resistor determines the physical size and type needed for the circuit. This circuit is shown in figure 3-67.

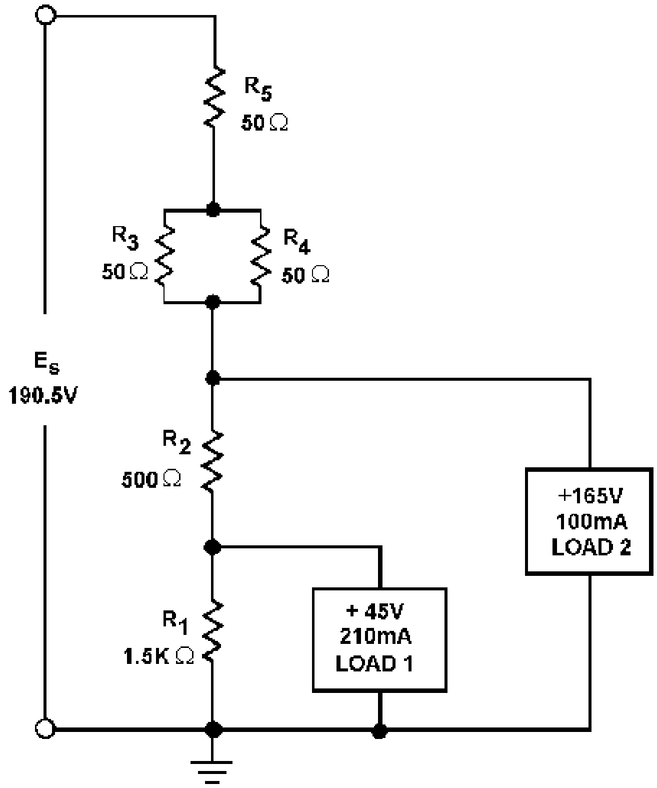


Figure 3-67.—Practical example of a voltage divider.

Q53. In figure 3-67, why is the value of R_1 calculated first?

Q54. In figure 3-67, how is (a) the current through R_2 and (b) the voltage drop across R_2 computed?

Q55. In figure 3-67, what is the power dissipated in R_1?

Q56. In figure 3-67, what is the purpose of the series-parallel network R_3, R_4, and R_5?

Q57. In figure 3-67, what should be the minimum wattage ratings of R_3 and R_5?

Q58. If the load requirement consists of both positive and negative voltages, what technique is used in the voltage divider to supply the loads from a single voltage source?

EQUIVALENT CIRCUIT TECHNIQUES

The circuit solutions that you have studied up to this point have been obtained mainly through the use of formulas derived from Ohm's law. As in many other fields of science, electricity has its share of special shortcut methods. Some of the special circuit analysis techniques are: THEVENIN'S THEOREM, which uses a process of circuit reduction to Thevenin's equivalent circuit; and NORTON'S THEOREM, which is reduction of a circuit to Norton's equivalent. Another method is called LOOP ANALYSIS. This uses Kirchhoff's voltage law to simultaneously solve problems in parallel branches of a circuit. The use of these methods should be reserved until you have become thoroughly familiar with the methods covered thus far in this chapter. You may want to explore some of the special techniques later in your career.

ELECTRICAL SAFETY

Safety precautions must always be observed by persons working around electric circuits and equipment to avoid injury from electric shock. Detailed safety precautions are contained in NAVMAT P-5l00, *Safety Precautions for Shore Activities* and OPNAVINST 5l00-19, *Navy Safety Precautions for Forces Afloat*.

The danger of shock from a 450-volt ac electrical service system is well recognized by operating personnel. This is shown by the relatively low number of reports of serious shock received from this voltage, despite its widespread use. On the other hand, a number of fatalities have been reported due to contact with low-voltage circuits. Despite a fairly widespread, but totally unfounded, popular belief to the contrary, low-voltage circuits (115 volts and below) are very dangerous and can cause death when the resistance of the body is lowered. Fundamentally, current, rather than voltage, is the measure of shock intensity. The passage of even a very small current through a vital part of the human body can cause DEATH. The voltage necessary to produce the fatal current is dependent upon the resistance of the body, contact conditions, the path through the body, etc. For example, when a 60-hertz alternating current, is passed through a human body from hand to hand or from hand to foot, and the current is gradually increased, it will cause the following effects: At about 1 milliampere (0.001 ampere), the shock can be felt; at about 10 milliamperes (0.01 ampere), the shock is of sufficient intensity to prevent voluntary control of the muscles; and at about 100 milliamperes (0.1 ampere) the shock is fatal if it lasts for 1 second or more. The above figures are the results of numerous investigations and are approximate because individuals differ in their resistance to electrical shock. It is most important to recognize that the resistance of the human body cannot be relied upon to prevent a fatal shock from 115 volts or less—FATALITIES FROM VOLTAGES AS LOW AS 30 VOLTS HAVE BEEN RECORDED. Tests have shown that body resistance under unfavorable conditions may be as low as 300 ohms, and possibly as low as 100 ohms from temple to temple if the skin is broken.

Conditions aboard ship add to the chance of receiving an electrical shock. Aboard ship the body is likely to be in contact with the metal structure of the ship and the body resistance may be low because of perspiration or damp clothing. Extra care and awareness of electrical hazards aboard ship are needed.

Short circuits can be caused by accidentally placing or dropping a metal tool, rule, flashlight case, or other conducting article across an energized line. The arc and fire which result, even on relatively low-voltage circuits, may cause extensive damage to equipment and serious injury to personnel.

Since ship service power distribution systems are designed to be ungrounded, many persons believe it is safe to touch one conductor, since no electrical current would flow. This is not true, since the distribution system is not totally isolated from the hull of the ship. If one conductor of an ungrounded electrical system is touched while the body is in contact with the hull of the ship or other metal equipment enclosure, a fatal electric current may pass through the body. ALL LIVE ELECTRIC CIRCUITS SHALL BE TREATED AS POTENTIAL HAZARDS AT ALL TIMES.

DANGER SIGNALS

Personnel should constantly be on the alert for any signs which might indicate a malfunction of electric equipment. Besides the more obvious visual signs, the reaction of other senses, such as hearing, smell, and touch, should also make you aware of possible electrical malfunctions. Examples of signs which you must be alert for are: fire, smoke, sparks, arcing, or an unusual sound from an electric motor.

Frayed and damaged cords or plugs; receptacles, plugs, and cords which feel warm to the touch; slight shocks felt when handling electrical equipment; unusually hot running electric motors and other electrical equipment; an odor of burning or overheated insulation; electrical equipment which either fails to operate or operates irregularly; and electrical equipment which produces excessive vibrations are also indications of malfunctions. When any of the above signs are noted, they are to be reported immediately to a qualified technician. DO NOT DELAY. Do not operate faulty equipment. Above all, do not attempt to make any repairs yourself if you are not qualified to do so. Stand clear of any suspected hazard and instruct others to do likewise.

- Warning Signs—They have been placed for your protection. To disregard them is to invite personal injury as well as possible damage to equipment. Switches and receptacles with a temporary warning tag, indicating work is being performed, are not to be touched.

- Working Near Electrical Equipment—When work must be performed in the immediate vicinity of electrical equipment, check with the technician responsible for the maintenance of the equipment so you can avoid any potential hazards of which you may not be immediately aware.

- Authorized Personnel Only—Because of the danger of fire, damage to equipment, and injury to personnel, all repair and maintenance work on electrical equipment shall be done only by authorized persons. Keep your hands off of all equipment which you have not been specifically authorized to handle. Particularly stay clear of electrical equipment opened for inspection, testing, or servicing.

- Circuit Breakers and Fuses—Covers for all fuse boxes, junction boxes, switch boxes, and wiring accessories should be kept closed. Any cover which is not closed or is missing should be reported to the technician responsible for its maintenance. Failure to do so may result in injury to personnel or damage to equipment in the event accidental contact is made with exposed live circuits.

ELECTRICAL FIRES

Carbon dioxide (CO_2) is used in fighting electrical fires. It is nonconductive and, therefore, the safest to use in terms of electrical safety. It also offers the least likelihood of damaging equipment. However, if the discharge horn of a CO_2 extinguisher is allowed to accidentally touch an energized circuit, the horn may transmit a shock to the person handling the extinguisher.

The very qualities which cause CO_2 to be a valuable extinguishing agent also make it dangerous to life. When it replaces oxygen in the air to the extent that combustion cannot be sustained, respiration also cannot be sustained. Exposure of a person to an atmosphere of high concentration of CO_2 will cause suffocation.

FIRST AID FOR ELECTRIC SHOCK

A person who has stopped breathing is not necessarily dead, but is in immediate danger. Life is dependent upon oxygen, which is breathed into the lungs and then carried by the blood to every body cell. Since body cells cannot store oxygen, and since the blood can hold only a limited amount (and that only for a short time), death will surely result from continued lack of breathing.

However, the heart may continue to beat for some time after breathing has stopped, and the blood may still be circulated to the body cells. Since the blood will, for a short time, contain a small supply of oxygen, the body cells will not die immediately. For a very few minutes, there is some chance that the person's life may be saved.

The process by which a person who has stopped breathing can be saved is called ARTIFICIAL VENTILATION (RESPIRATION).

The purpose of artificial ventilation is to force air out of the lungs and into the lungs, in rhythmic alternation, until natural breathing is reestablished. Artificial ventilation should be given only when natural breathing has stopped; it should NOT be given to any person who is breathing naturally. You should not assume that an individual who is unconscious due to electrical shock has stopped breathing. To tell if someone suffering from an electrical shock is breathing, place your hands on the person's sides, at the level of the lowest ribs. If the victim is breathing, you will usually be able to feel the movement. Remember: DO NOT GIVE ARTIFICIAL VENTILATION TO A PERSON WHO IS BREATHING NATURALLY.

Records show that seven out of ten victims of electric shock were revived when artificial respiration was started in less than 3 minutes. After 3 minutes, the chances of revival decrease rapidly.

Once it has been determined that breathing has stopped, the person nearest the victim should start the artificial ventilation without delay and send others for assistance and medical aid. The only logical, permissible delay is that required to free the victim from contact with the electricity in the quickest, safest way. This step, while it must be taken quickly, must be done with great care; otherwise, there may be two victims instead of one. In the case of portable electric tools, lights, appliances, equipment, or portable outlet extensions, this should be done by turning off the supply switch or by removing the plug from its receptacle. If the switch or receptacle cannot be quickly located, the suspected electrical device may be pulled free of the victim. Other persons arriving on the scene must be clearly warned not to touch the suspected equipment until it is deenergized. Aid should be enlisted to unplug the device as soon as possible. The injured person should be pulled free of contact with stationary equipment (such as a bus bar) if the equipment cannot be quickly deenergized, or if considerations of military operation or unit survival prevent immediate shutdown of the circuits.

This can be done quickly and safely by carefully applying the following procedures:

1. Protect yourself with dry insulating material.

2. Use a dry board, belt, clothing, or other available nonconductive material to free the victim from electrical contact. DO NOT TOUCH THE VICTIM UNTIL THE SOURCE OF ELECTRICITY HAS BEEN REMOVED.

Once the victim has been removed from the electrical source, it should be determined, if the person is breathing. If the person is not breathing, a method of artificial ventilation is used.

Sometimes victims of electrical shock suffer cardiac arrest (heart stoppage) as well as loss of breathing. Artificial ventilation alone is not enough in cases where the heart has stopped. A technique known as Cardiopulmonary Resuscitation (CPR) has been developed to provide aid to a person who has stopped breathing and suffered a cardiac arrest. Because you most likely will be working in the field of electricity, the risk of electrical shock is higher than most other Navy occupations. You should, at your earliest opportunity, learn the technique of CPR.

CPR is relatively easy to learn and is taught in courses available from the American Red Cross, some Navy Medical Departments, and in the *Standard First Aid Training Course* (NAVEDTRA 12081).

Q59. Is it considered safe for a person to touch any energized low-voltage conductor with the bare hand?

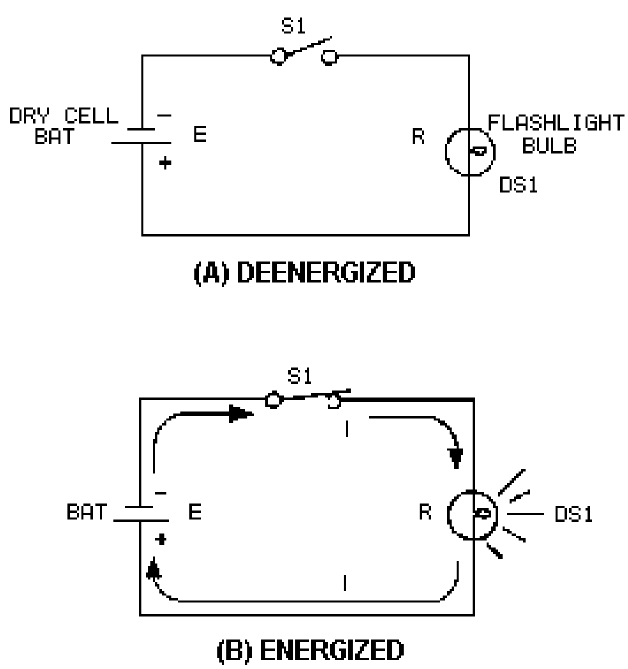
Q60. What should you do if you become aware of a possible malfunction in a piece of electrical equipment?

Q61. Who should perform CPR?

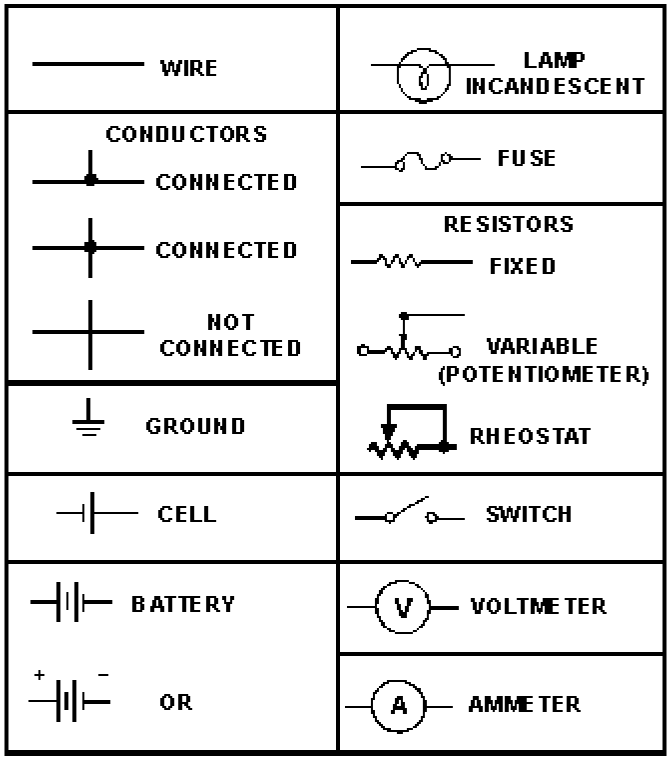
SUMMARY

With the completion of this chapter you have gained a basic understanding of dc circuits. The information you have learned will provide you with a firm foundation for continuing your study of electricity. The following is a summary of the important points in the chapter.

A BASIC ELECTRIC CIRCUIT consists of a source of electrical energy connected to a load. The load uses the energy and changes it to a useful form.



A SCHEMATIC DIAGRAM is a "picture" of a circuit, which uses symbols to represent components. The space required to depict an electrical or electronic circuit is greatly reduced by the use of a schematic.



<u>VOLTAGE (E)</u> is the electrical force or pressure operating in a circuit.

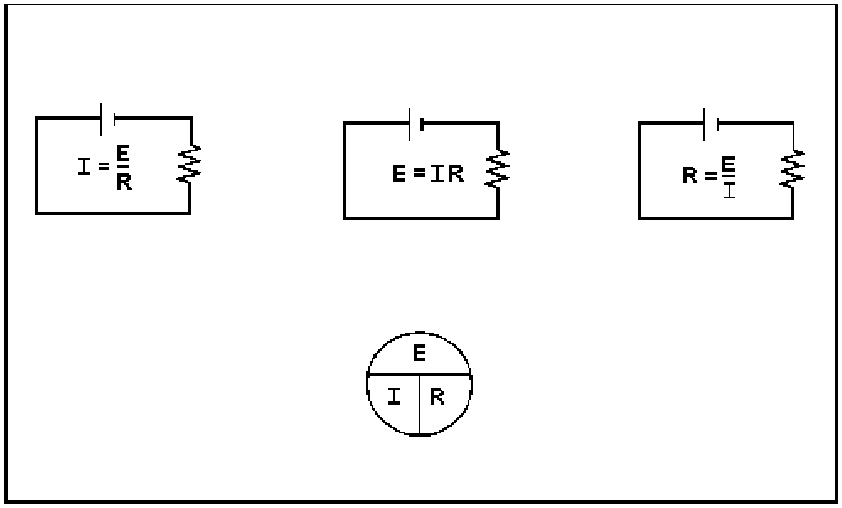
<u>AN AMPERE (A)</u> represents the current flow produced by one volt working across one ohm of resistance.

<u>RESISTANCE (R)</u> is the opposition to current. It is measured in ohms (Ω). One ohm of resistance will limit the current produced by one volt to a level of one ampere.

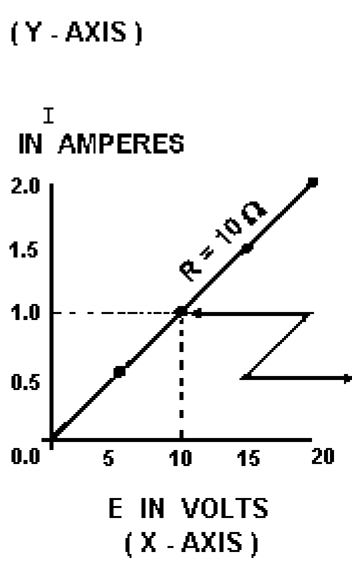
<u>THE OHM'S FORMULA</u> can be transposed to find one of the values in a circuit if the other two values are known. You can transpose the Ohm's law formula

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

mathematically, or you can use the Ohm's law figure to determine the mathematical relationship between R, E, and I.



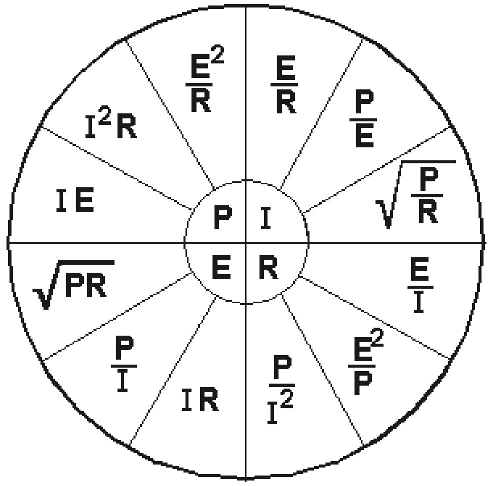
GRAPHICAL ANALYSIS of the relationship between R, E, and I can be studied by plotting these quantities on a graph. Such a graph is useful for observing the characteristics of an electrical device.



R = 10 Ω	
E	I
0	0.0
5	0.5
10	1.0
15	1.5
20	2.0

POWER is the rate of doing work per unit of time. The time required to perform a given amount of work will determine the power expended. As a formula, P = E x I, where P = power in watts, E = voltage in volts, and I = current in amperes.

THE FOUR BASIC ELECTRICAL QUANTITIES are P, I, E, R. Any single unknown quantity can be expressed in terms of any two of the other known quantities. The formula wheel is a simple representation of these relationships.



POWER RATING in watts indicates the rate at which a device converts electrical energy into another form of energy. The power rating of a resistor indicates the maximum power the resistor can withstand without being destroyed.

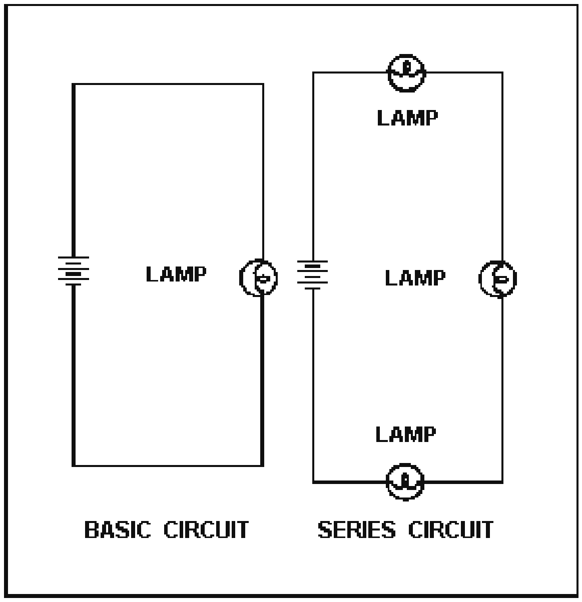
POWER USED by an electrical device is measured in watt-hours. One watt-hour is equal to one watt used continuously for one hour.

THE EFFICIENCY of an electrical device is equal to the electrical power converted into useful energy divided by the electrical power supplied to the device.

$$\text{EFF} = \frac{\text{Power converted}}{\text{Power used}}$$

HORSEPOWER is a unit of measurement often used to rate electrical motors. It is a unit of work. One horsepower is equal to 746 watts.

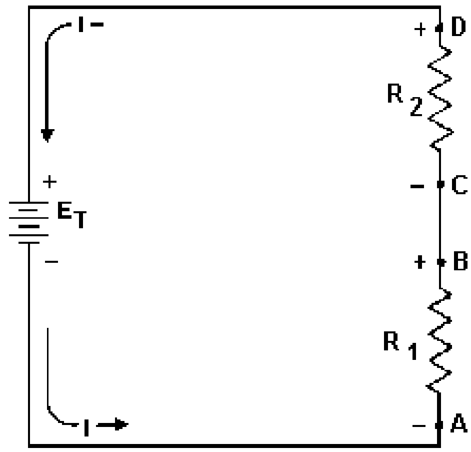
A SERIES CIRCUIT is defined as a circuit that has only one path for current flow.



RULES FOR SERIES DC CIRCUITS:

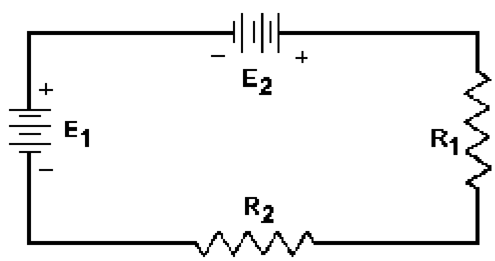
- The same current flows through each part of a series circuit.
- The total resistance of a series circuit is equal to the sum of the individual resistances.
- The total voltage across a series circuit is equal to the sum of the individual voltage drops.
- The voltage drop across a resistor in a series circuit is proportional to the ohmic value of the resistor.
- The total power in a series circuit is equal to the sum of the individual power used by each circuit component.

KIRCHHOFF'S VOLTAGE LAW states: The algebraic sum of the voltage drops in any closed path in a circuit and the electromotive forces in that path is equal to zero, or $E_a + E_b + E_c + ... E_n = 0$.

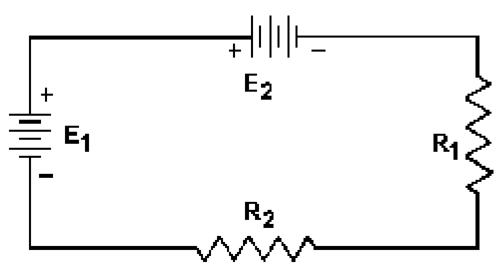


VOLTAGE POLARITIES must be used when applying Kirchhoff's voltage law. The point at which current enters a load (resistor) is considered negative with respect to the point at which current leaves the load.

SERIES AIDING VOLTAGES cause current to flow in the same direction; thus the voltages are added.



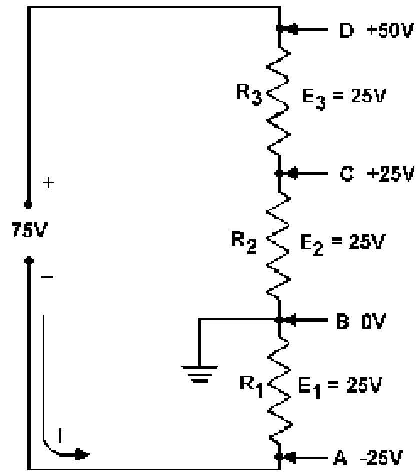
SERIES AIDING



SERIES OPPOSING

SERIES OPPOSING VOLTAGES tend to force current to flow in opposite directions; thus the equivalent voltage is the difference between the opposing voltages.

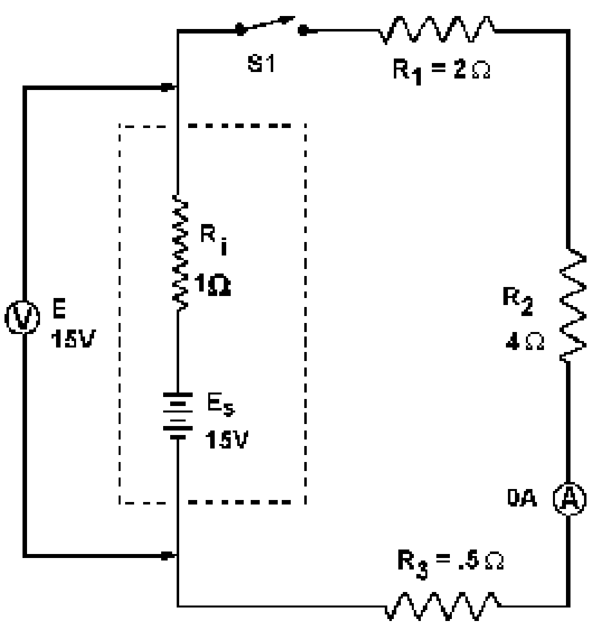
A REFERENCE POINT is a chosen point in a circuit to which all other points are compared.

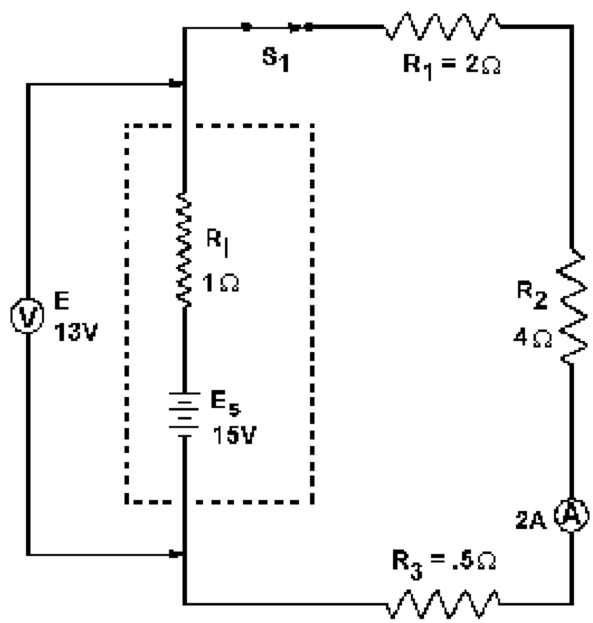


AN OPEN CIRCUIT is one in which a break exists in the complete conducting pathway.

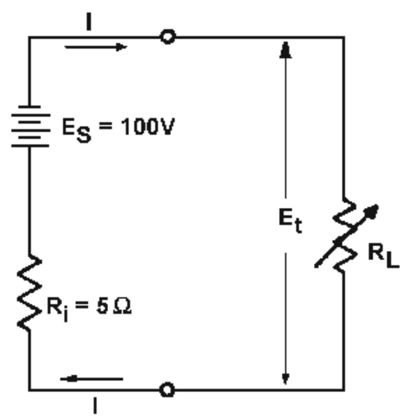
A SHORT CIRCUIT is an accidental path of low resistance which passes an abnormally high amount of current.

INTERNAL RESISTANCE causes a drop in the terminal voltage of a source as current flows through the source. The decrease in terminal voltage is caused by the voltage drop across the internal resistance. All sources of electromotive force have some form of internal resistance.





HIGH EFFICIENCY in a circuit is achieved when the resistance of the load is high with respect to the resistance of the source.

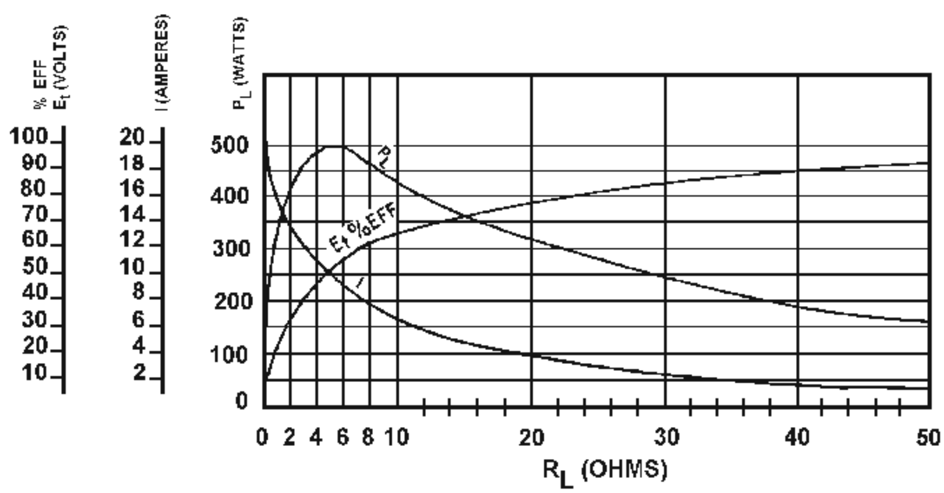


E_S = OPEN - CIRCUIT VOLTAGE OF SOURCE
R_i = INTERNAL RESISTANCE OF SOURCE
E_t = TERMINAL VOLTAGE
R_L = RESISTANCE OF LOAD
P_L = POWER USED IN LOAD
I = CURRENT FROM SOURCE
% EFF. = PERCENTAGE OF EFFICIENCY

(A)
CIRCUIT AND SYMBOL DESIGNATION

R_L	E_t	I	P_L	%EFF.
0	0	20	0	0
1	16.7	16.7	278.9	16.7
2	28.6	14.3	409	28.6
3	37.5	12.5	468.8	37.5
4	44.4	11.1	492.8	44.4
5	50	10	500	50
6	54.5	9.1	496.0	54.5
7	58.3	8.3	483.9	58.3
8	61.6	7.7	474.3	61.6
9	64.3	7.1	456.5	64.3
10	66.7	6.7	446.9	66.7
20	80	4	320	80
30	85.7	2.9	248.5	85.7
40	88.9	2.2	195.6	88.9
50	90.9	1.9	172.7	90.9

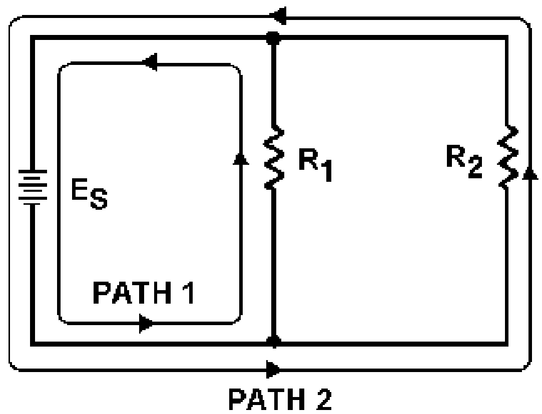
(B)
CHART



(C)
GRAPH

POWER TRANSFER in a circuit is highest when the resistance of the load equals the resistance of the source.

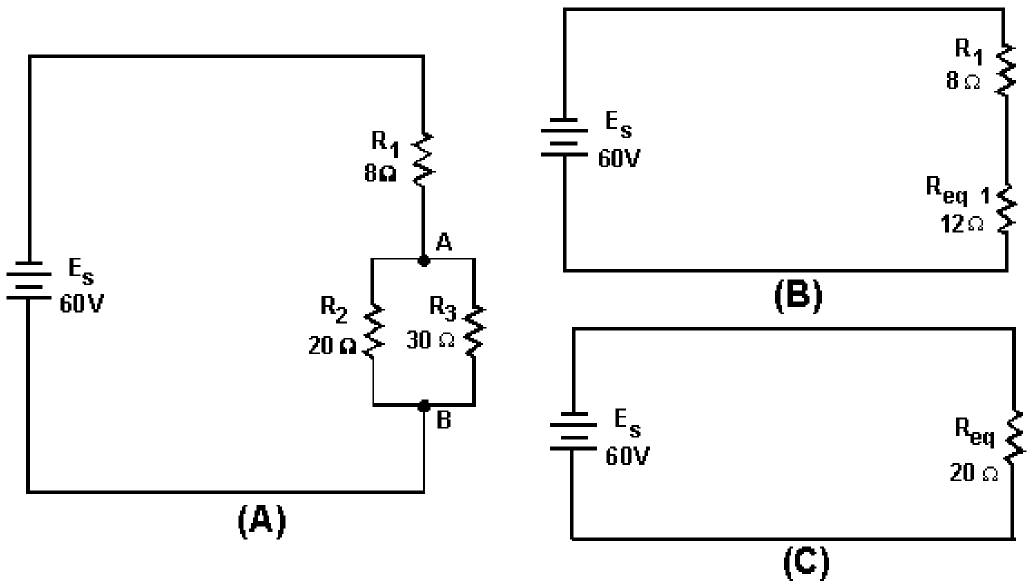
A PARALLEL CIRCUIT is a circuit having more than one current path connected to a common voltage source.



RULES FOR PARALLEL DC CIRCUITS:

- The same voltage exists across each branch of a parallel circuit and is equal to the source voltage.
- The current through a branch of a parallel network is inversely proportional to the amount of resistance of the branch.
- The total current of a parallel circuit is equal to the sum of the currents of the individual branches of the circuit.
- The total resistance of a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual resistances of the circuit.
- The total power consumed in a parallel circuit is equal to the sum of the power consumptions of the individual resistances.

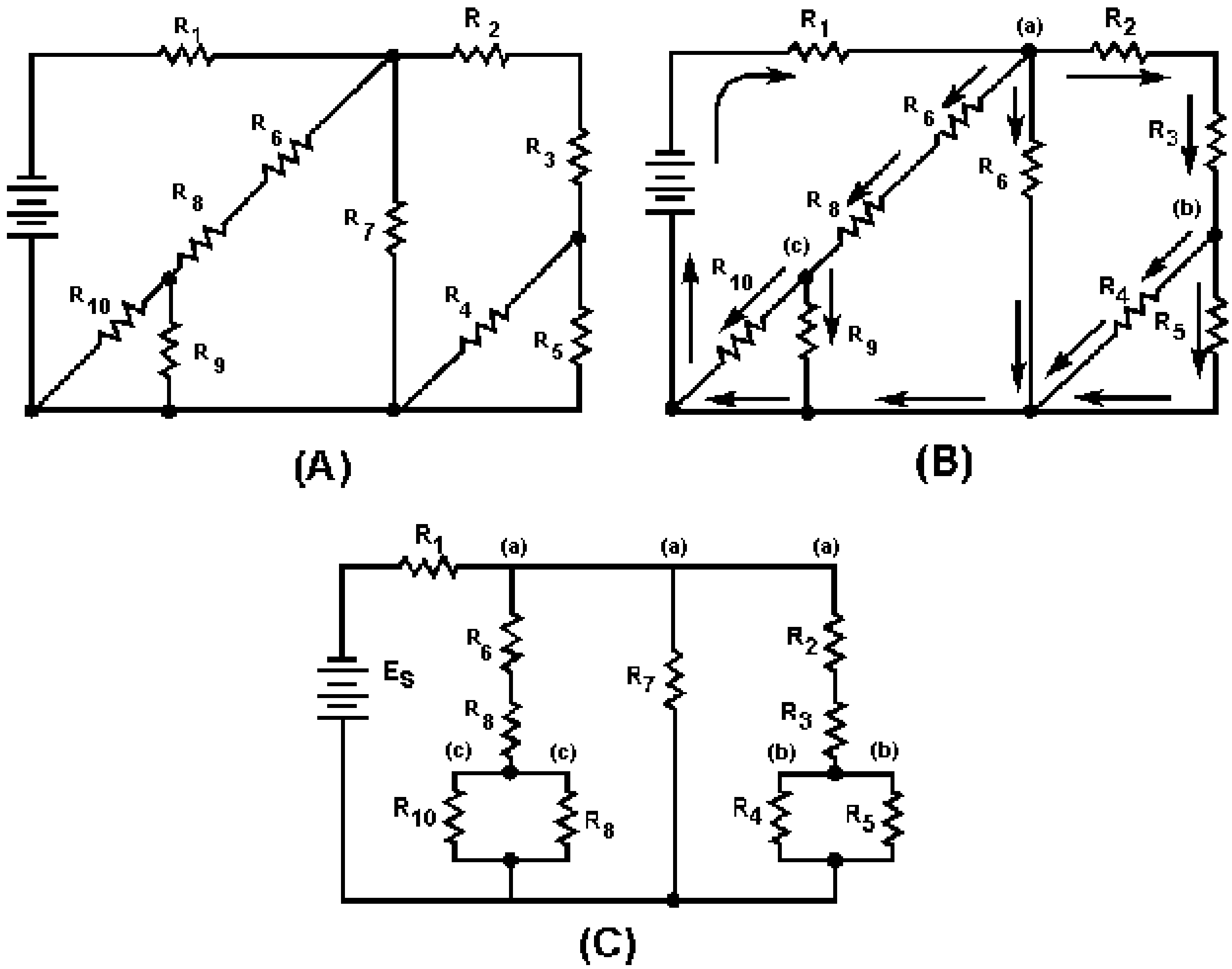
THE SOLUTION OF A COMBINATION CIRCUIT is a matter of applying the laws and rules for series and parallel circuits as applicable.



ALL PARALLEL CIRCUITS ARE COMBINATION CIRCUITS when the internal resistance of the source is taken into account.

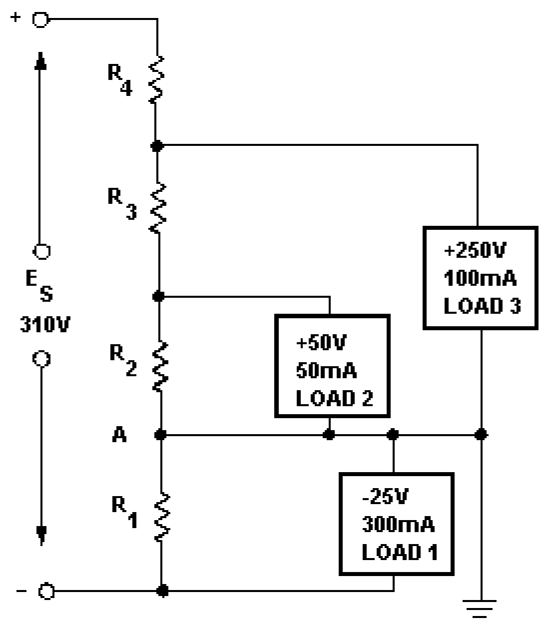
REDRAWING CIRCUITS FOR CLARITY is accomplished in the following steps:

1. Trace the current paths in the circuit.
2. Label the junctions in the circuit.
3. Recognize points which are at the same potential.
4. Visualize rearrangements, "stretching" or "shrinking," of connecting wires.
5. Redraw the circuit into simpler form (through stages if necessary).



EQUIPMENT PROTECTION from short-circuit current is accomplished by use of fuses and other circuit protection devices.

A VOLTAGE DIVIDER is a series circuit in which desired portions of the source voltage may be tapped off for use in equipment. Both negative and positive voltage can be provided to the loads by the proper selection of the reference point (ground).



ELECTRICAL SAFETY PRECAUTIONS must be observed. A fatal shock can occur from 0.1 ampere of current. Voltages as low as 30 volts have been recorded as causing sufficient current to be fatal.

ALL LIVE ELECTRICAL CIRCUITS shall be treated as potential hazards at all times.

ELECTRONIC OR ELECTRICAL EQUIPMENT discovered to be faulty or unsafe should be reported immediately to proper authority.

ELECTRICAL OR ELECTRONIC EQUIPMENT should be used and repaired by authorized personnel only.

A CO_2 EXTINGUISHER should be used to extinguish electrical fires.

FIRST AID FOR ELECTRICAL SHOCK includes the following actions:

- Remove the victim from the source of the shock.
- Check the victim to see if the person is breathing.
- If the victim is not breathing, give artificial ventilation. The preferred method is mouth-to-mouth.
- CPR may be necessary if the heartbeat has stopped, but do not attempt this unless you have been trained in its use. OBTAIN MEDICAL ASSISTANCE AS SOON AS POSSIBLE.

ANSWERS TO QUESTIONS Q1. THROUGH Q61.

A1. (a) DS1, the flashlight bulb (b) BAT, the dry cell

A2. The path for current is incomplete; or, there is no path for current with S1 open.

A3. A schematic diagram.

A4. (a) Current increases (b) Current decreases

A5. (a) Current decreases (b) Current increases

A6.

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

A7. 1.25 amperes.

A8. 4 amperes.

A9. Power.

A10. By changing the circuit resistance or the voltage of the power source.

A11.

$$P = E \times I, \quad P = \frac{E^2}{R}, \quad P = I^2 \times R$$

A12. 6 amperes.

A13. A wirewound resistor.

A14. 1 kilowatt.

A15. 8,952 watt hours or 8.952 kWh.

A16. 942 (rounded to 3 places).

A17.

(a). 160 ohms
(b). 480 ohms

A18.

E_1 = 60 volts
E_2 = 180 volts
E_3 = 240 volts

A19.

E_1 = 80 volts
E_2 = 240 volts
E_3 = 320 volts

A20. The source voltage would have to be increased to 640 volts.

A21.

(a) 330 volts

(b) E_1 = 150 volts
E_2 = 180 volts

(c) 1.98 kilowatts

(d) P_1 = 900 watts
P_2 = 1.08 kilowatts

A22. The point at which current enters the resistor is assigned a negative polarity and the point at which current leaves the resistor is assigned a positive polarity.

A23. 2 amperes.

A24. 120 volts.

A25. 50 volts.

A26. Zero volts.

A27. A circuit where there is no longer a complete path for current flow.

A28. An accidental path of low resistance which passes an abnormally high amount of current.

A29. The internal (source) resistance of the battery will drop some of the voltage.

A30. When the load resistance equals the source resistance.

A31. 50 percent.

A32.

$$98 \text{ percent } \left(\frac{12.25 \text{ watts}}{12.5 \text{ watts}} \times 100 \right)$$

A33. *60 volts.*

A34. *Total current in a series circuit flows through every circuit component but in a parallel circuit total current divides among the available paths.*

A35. *Whether the current is entering the junction (+) or leaving the junction (-).*

A36.

$$25 \text{ ohms } \left(R_{eq} = \frac{R}{N} \right)$$

A37.

$$6\ k\Omega \left(R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \right) \quad \text{(use powers of tens)}$$

A38.

$$7.5\ k\Omega \left(R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2} \right)$$

A39. *Equivalent resistor or R_{eq}.*

A40. *In both cases all the power used in the circuit must come from the source.*

A41.

$$R_T = 12\Omega \quad \left(\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)$$

$$E_S = 120V \quad \left(E_S = E_{R3} = \sqrt{P_{R3} \times R_3} \right)$$

$$I_{R2} = 4A \quad \left(I_{R2} = \frac{E_S}{R_2} \right)$$

A42. *$P_T = 60$ W, $E_{R2} = 10$ V.*

A43. *4Ω.*

A44. *25Ω.*

A45. Because of the 2-volt drop across the internal resistance, only 48 volts is available for the rest of the circuit.

A46. (a) Total resistance increases, total current decreases (b) Total resistance becomes infinite, total current is equal to zero

A47. (a) Total resistance decreases, total current increases (b) Total resistance decreases, total current increases

A48. None.

A49. The source voltage and load requirements (voltage and current).

A50. 45 mA rule-of-thumb.

A51. 2 kΩ.

A52. 495 mA.

A53. R_1 is the bleeder resistor. Bleeder current must be known before any of the remaining divider resistor ohmic values can be computed.

A54. (a) By adding the bleeder current (I_{R1}) and the current through load 1(b) By subtracting the voltage of load 1 from the voltage of load 2.

A55. 1.35 watts.

A56. The series-parallel network drops the remaining source voltage and is used to take the place of a single resistor (75 ohms) when the required ohmic value is not available in a single resistor.

A57. R_3 = 2 watts; R_5 = 6 watts.

A58. The ground (reference point) is placed in the proper point in the voltage divider so that positive and negative voltages are supplied.

A59. NEVER! All energized electric circuits should be considered potentially dangerous.

A60. You should immediately report this condition to a qualified technician.

A61. Only trained, qualified personnel.