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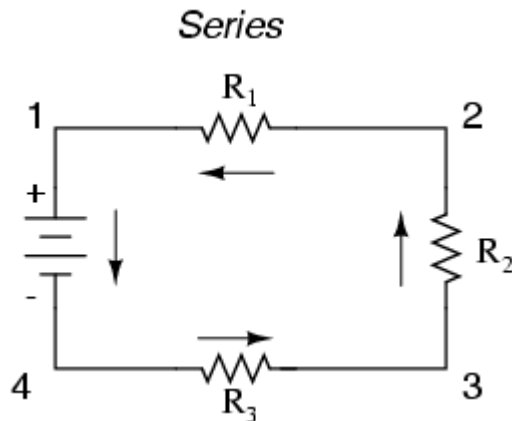
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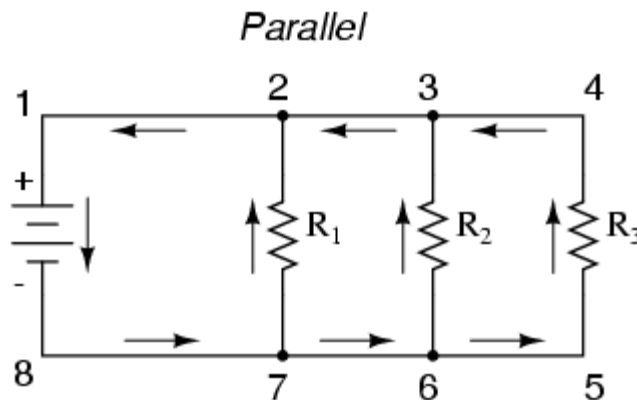
## Characteristics of Series-Parallel Circuits

With simple series circuits, all components are connected end-to-end to form only one path for electrons to flow through the circuit:



**Figure 1: Simple series circuit.**

With simple parallel circuits, all components are connected between the same two sets of electrically common points, creating multiple paths for electrons to flow from one end of the battery to the other:



**Figure 2: Simple parallel circuit.**

With each of these two basic circuit configurations, we have specific sets of rules describing voltage, current, and resistance relationships:

### Series Circuits:

- Voltage drops add to equal total voltage.

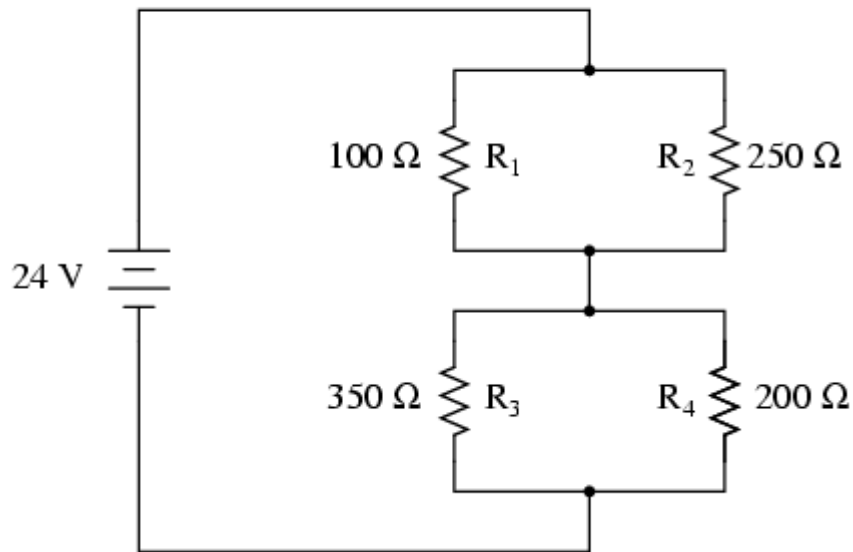
- All components share the same (equal) current.
- Resistances add to equal total resistance.

**Parallel Circuits:**

- All components share the same (equal) voltage.
- Branch currents add to equal total current.
- Resistances diminish to equal total resistance.

However, if circuit components are series-connected in some parts and parallel in others, we won't be able to apply a *single* set of rules to every part of that circuit. Instead, we will have to identify which parts of that circuit are series and which parts are parallel, then selectively apply series and parallel rules as necessary to determine what is happening. Take the following circuit, for instance:

*A series-parallel combination circuit*



**Figure 3: A series-parallel combination circuit**

This circuit is neither simple series nor simple parallel. Rather, it contains elements of both. The current exits the bottom of the battery, splits up to travel through  $R_3$  and  $R_4$ , rejoins, then splits up again to travel through  $R_1$  and  $R_2$ , then rejoins again to return to the top of the battery. There exists more than one path for current to travel (not series), yet there are more than two sets of electrically common points in the circuit (not parallel).

Because the circuit is a combination of both series and parallel, we cannot apply the rules for voltage, current, and resistance across the board to begin analysis like we could when the circuits were one way or the other. For instance, if the above circuit were simple series, we could just add up  $R_1$  through  $R_4$  to arrive at a total resistance, solve for total current, and then solve for all voltage drops. Likewise, if the above circuit were simple parallel, we could just solve for branch currents, add up branch currents to figure the total current, and then calculate total resistance from total voltage and total current. However, this circuit's solution will be more complex.

If we are able to identify which parts of the circuit are series and which parts are parallel, we can analyze it in stages, approaching each part one at a time, using the appropriate rules to determine the relationships of voltage, current, and resistance.

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. 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.

## ***Media Resources***

### **Internet Archive - FEDFLIX**

- Review of Series and Parallel Resistive Circuits (January 1, 1975)
  - <https://archive.org/details/gov.dod.dimoc.41464>

## 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 4(A) will be used to calculate various circuit quantities, such as resistance, current, voltage, and power.

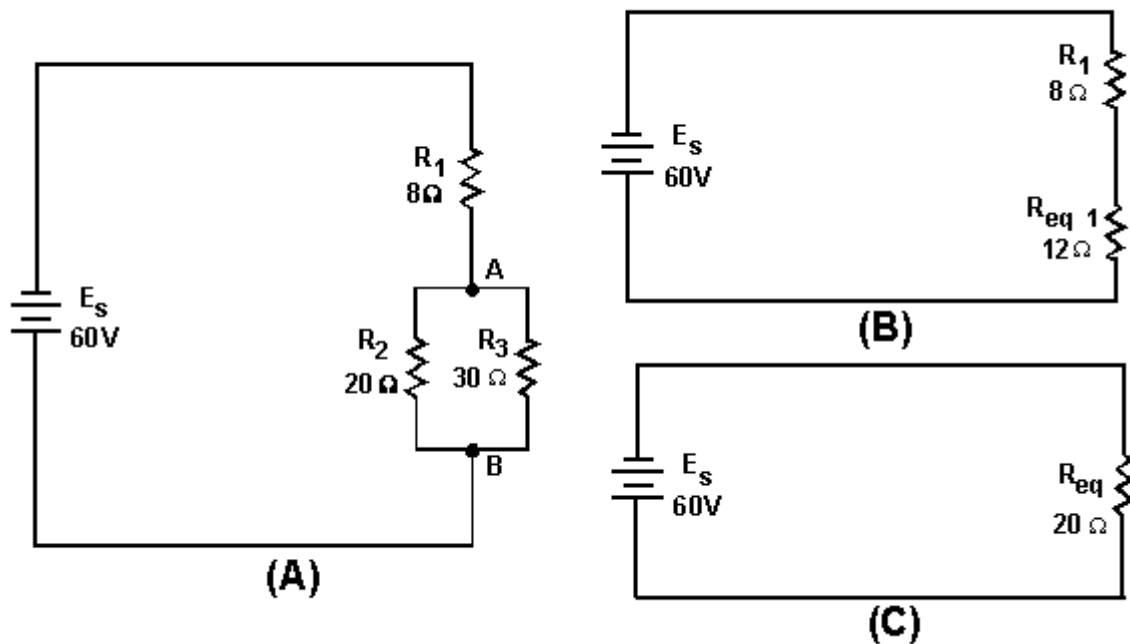


Figure 4: Example combination circuit.

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:**  $R_{eq1} = \frac{R_2 \times R_3}{R_2 + R_3}$  (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 4(B).

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

**Given:**  $R_1 = 8\Omega$  (Resistors in series)  
 $R_{eq1} = 12\Omega$

**Solution:**  $R_{eq} = R_1 + R_{eq1}$   
 $R_{eq} = 8\Omega + 12\Omega$   
 $R_{eq} = 20\Omega$   
 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 4(C).

To find total current in the circuit:

**Given:**  $E_s = 60V$   
 $R_T = 20\Omega$



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**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  $R_1$ ,  $R_2$ , and  $R_3$ , refer to Figure 4(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  $R_1$ :

**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 4(A). You know  $E_{R2}$  and  $E_{R3}$  from previous calculation.

**Given:**  $E_{R2} = 36V$   
 $E_{R3} = 36V$   
 $R_2 = 20\Omega$   
 $R_3 = 30\Omega$

**Solution:**  $I_{R2} = \frac{E_{R2}}{R_2}$  (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:**

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

**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 4, 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 5 is a typical combination circuit. To make sure you understand the techniques of solving for the unknown quantities, solve for  $E_{R_1}$ .

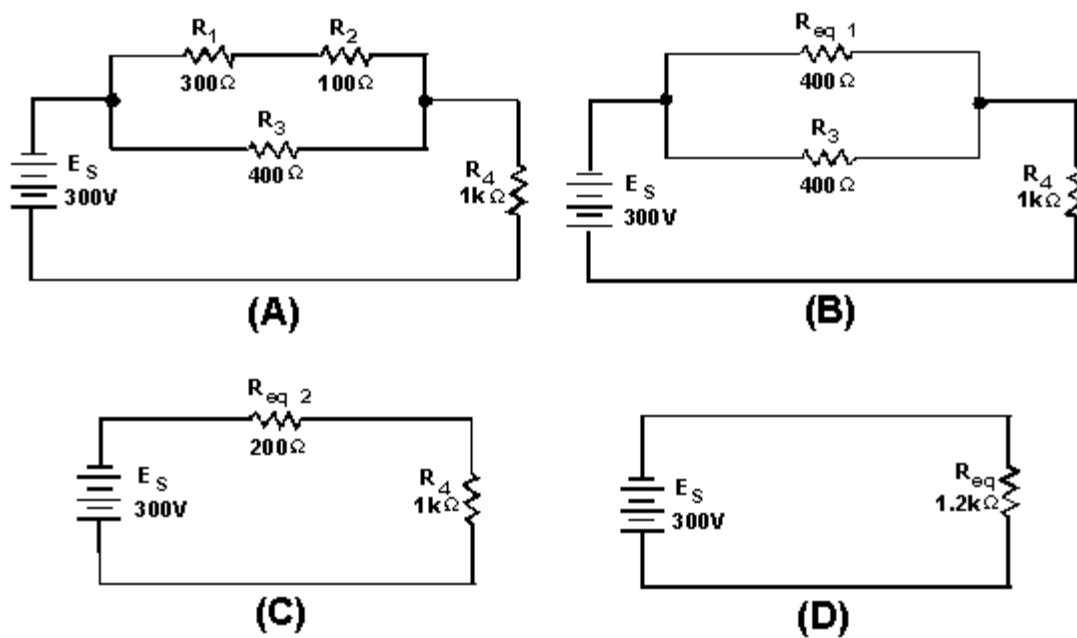


Figure 5: Combination practice circuit.

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

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 5(B).

**Given:**  $R_{eq1} = 400\Omega$   
 $R_3 = 400\Omega$

**Solution:**  $R_{eq2} = \frac{R}{N}$  (Equal resistors  
in parallel)  
 $R_{eq2} = \frac{400\Omega}{2}$   
 $R_{eq2} = 200\Omega$

Redraw the circuit as shown in Figure 5(C).

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

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

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

**Given:**  $E_s = 300V$   
 $R_{eq} = 1.2k\Omega$

**Solution:**  $I_T = \frac{E_s}{R_{eq}}$

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

$$I_T = 250mA$$

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

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

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

$$I_{Req1} = 125mA$$

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:**

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

**Solution:**

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

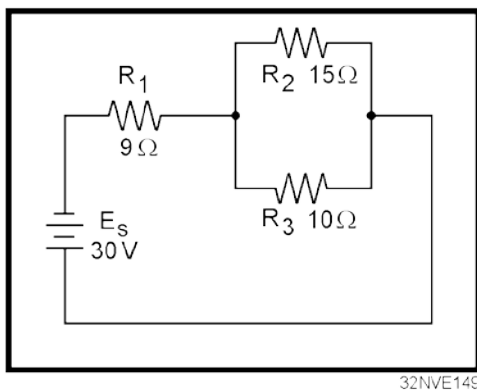
### ***Media Resources***

#### **Wisc-Online.com**

- [Series-Parallel DC Circuits Analysis](#)
- [Power Calculations in a Series/Parallel Circuit](#)
- [Effects of a Rheostat in a Series-Parallel Circuit](#)

### **Knowledge Check**

1. Refer to Figure 5(A). If the following resistors were replaced with the values indicated:  $R_1 = 900\Omega$ ,  $R_3 = 1\text{ k}\Omega$ , what is the total power in the circuit? What is  $E_{R2}$ ?



**Figure 6: Series-parallel circuit.**

2. What is the value of the total resistance (Figure 6)?

- a.  $3.6\Omega$
  - b.  $15\Omega$
  - c.  $34\Omega$
  - d.  $40\Omega$
3. What is the total power used in the circuit (Figure 6)?
- a. 1. 22.5 W
  - b. 2. 26.5 W
  - c. 3. 60.0 W
  - d. 4. 250.0 W
4. What is the total voltage drop across R3 (Figure 6)?
- a. 8 V
  - b. 12 V
  - c. 18 V
  - d. 30 V
5. Interactive circuit analysis from Wisc-Online.com
- a. [Series- Parallel Circuit Analysis Practice Problems – Circuit 2](#)
  - b. [Series-Parallel Circuit Analysis Practice Problems – Circuit 5](#)
  - c. [Series-Parallel Circuit Analysis Practice Problems – Circuit 6](#)

## 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.

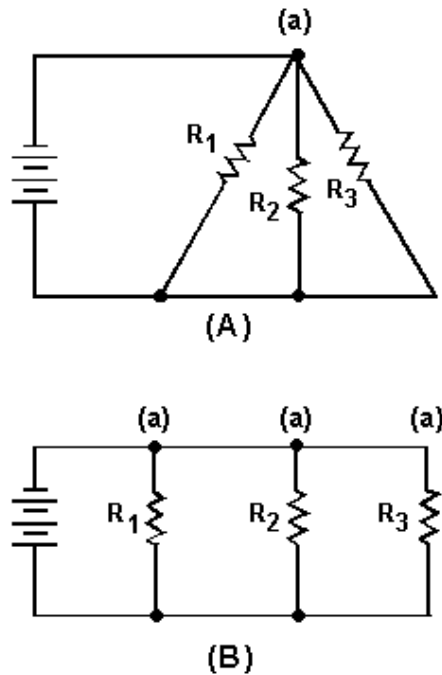
In actual practice the wired circuits and more complex schematics are rarely laid out in this simple form. For this reason, it is important for you to recognize that circuits can be drawn in a variety of ways, and to learn some of the techniques for redrawing them into their simplified form. When a circuit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

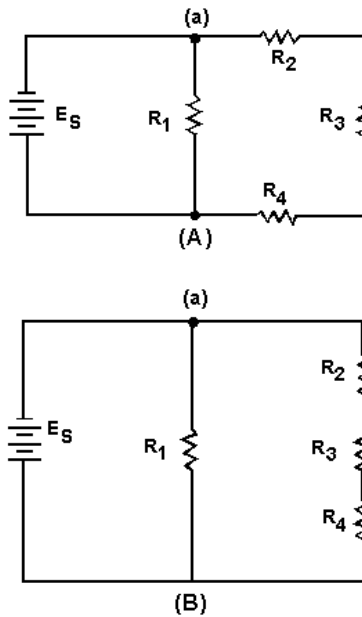


**Figure 7: Redrawing a simple parallel circuit.**

Figure 7(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 7(B).

While these circuits may appear to be different, the two drawings actually represent the same circuit. The drawing in Figure 7(B) is the familiar box-like structure and may be easier to work with. Figure 8(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 8(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 8: Redrawing a simple series-parallel**

**Redrawing Complex Circuits**

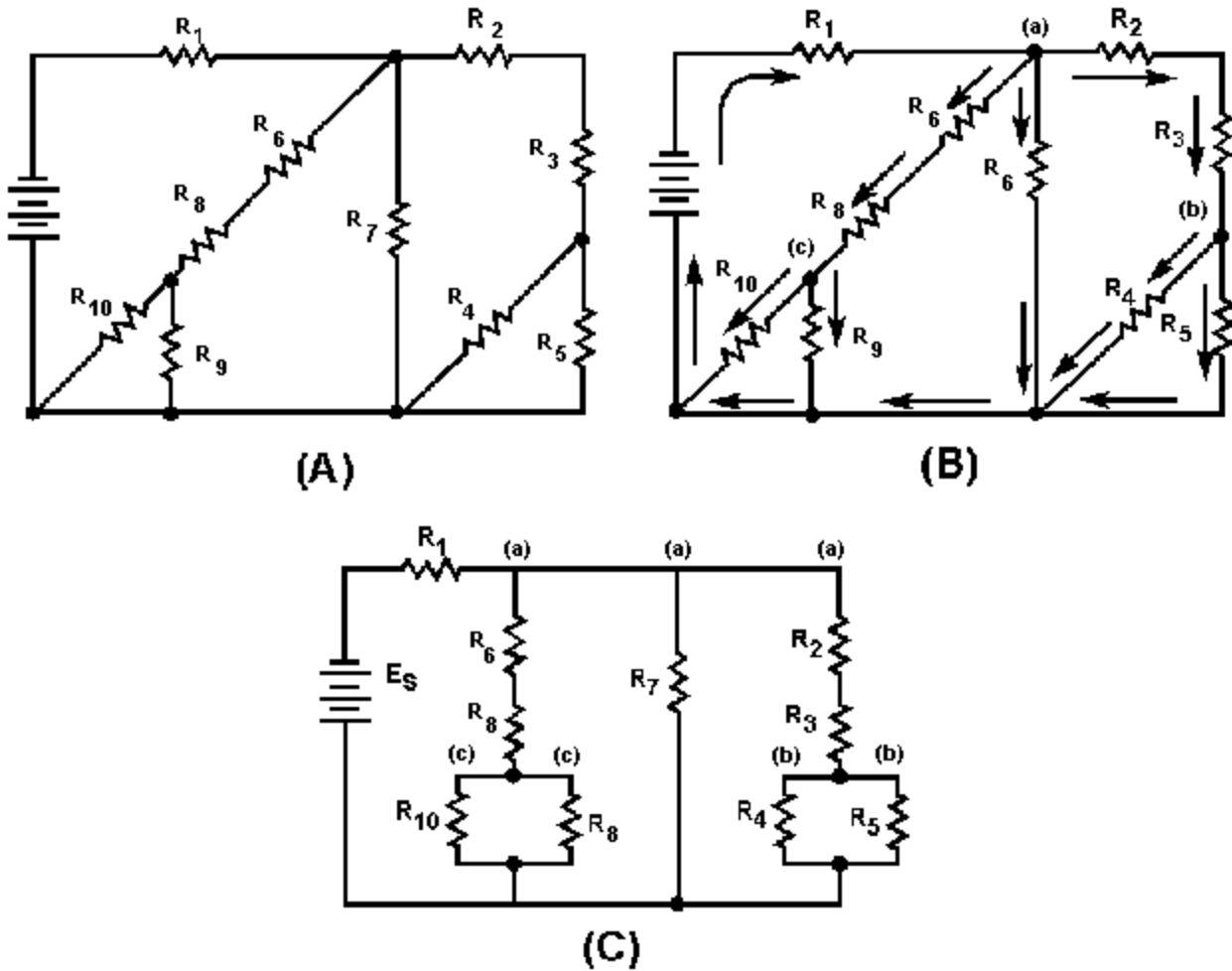


Figure 9: Redrawing a complex circuit.

Figure 9(A) shows a complex circuit that may be redrawn for clarification in the following steps.

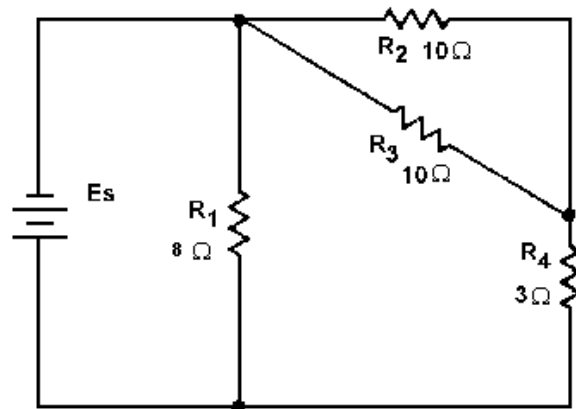
**NOTE:** As you redraw the circuit, draw it in simple box-like form. Each time you reach a junction, a new branch is created by stretching or shrinking the wires.

- 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).

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- 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 9(C).

It is much easier to recognize the series and parallel paths in the redrawn circuit.

**Knowledge Check**

1. What is the total resistance of the circuit shown in Figure 10? (Hint: Redraw the circuit to simplify and then use equivalent resistances to compute for  $R_T$ .)

**Troubleshooting Series-Parallel Circuits*****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.

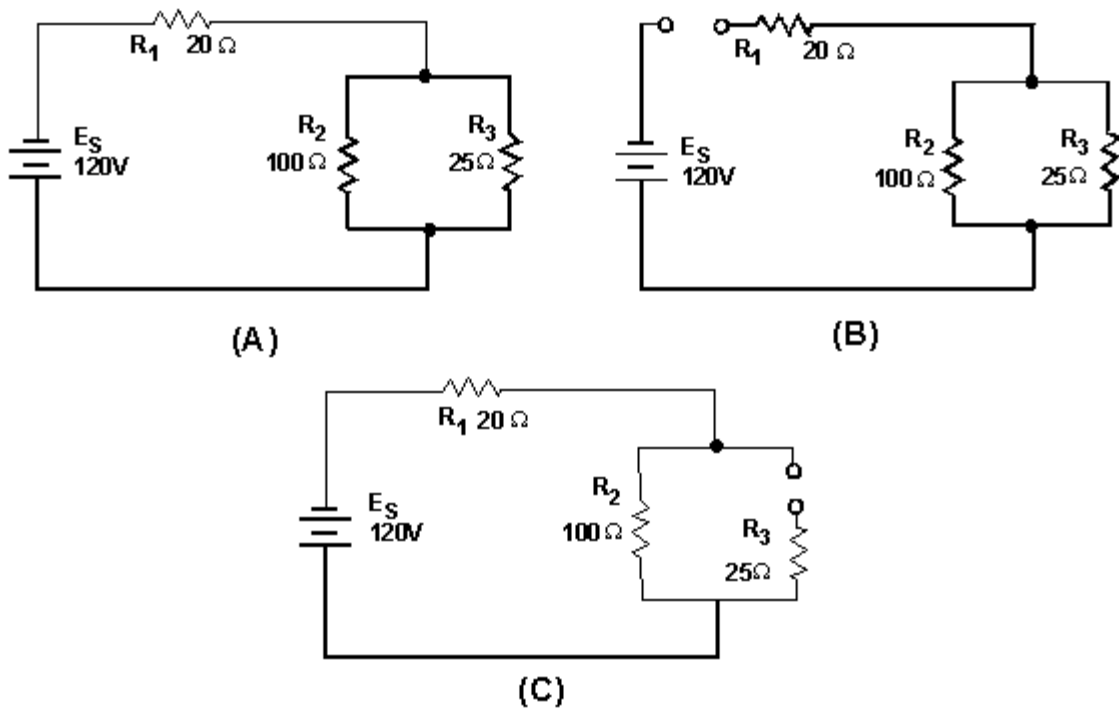


Figure 11. Series-parallel circuit with opens.

To clarify these points, Figure 11 illustrates a series parallel circuit. First the effect of an open in the series portion of this circuit will be examined. Figure 11(A) shows the normal circuit,  $R_T = 40$  ohms and  $I_T = 3$  amps. In Figure 11(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.

In Figure 11(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 12 shows a series-parallel network in which shorts are developed. In Figure 12 (A) the normal circuit is shown.  $R_T = 40$  ohms and  $I_T = 3$  amps.

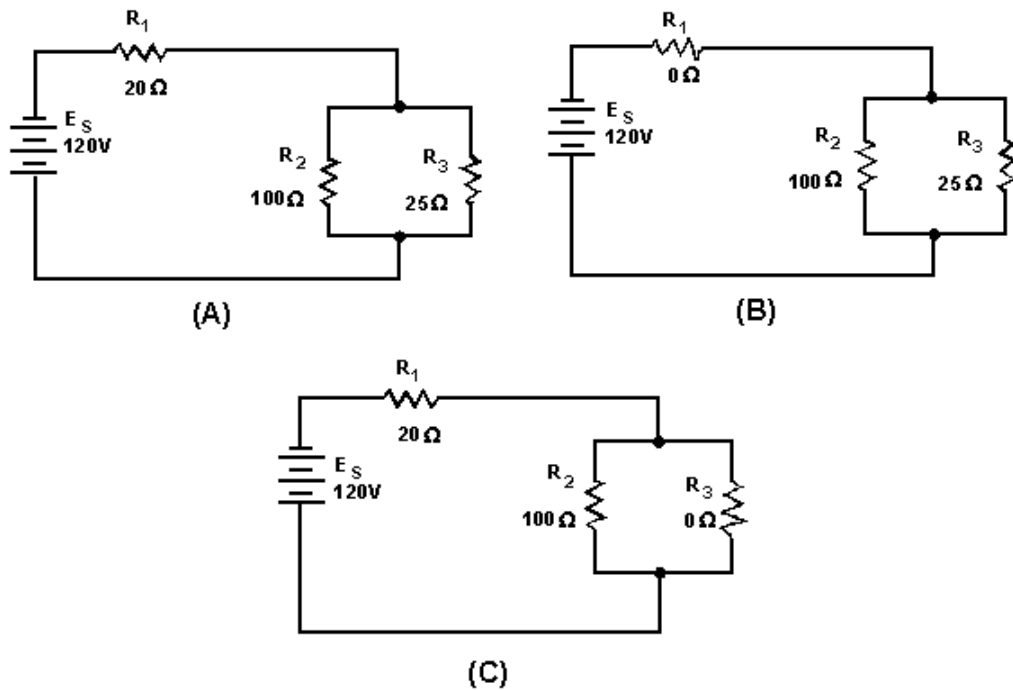


Figure 12: Series-parallel circuit with shorts.

In Figure 12 (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 12 (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.

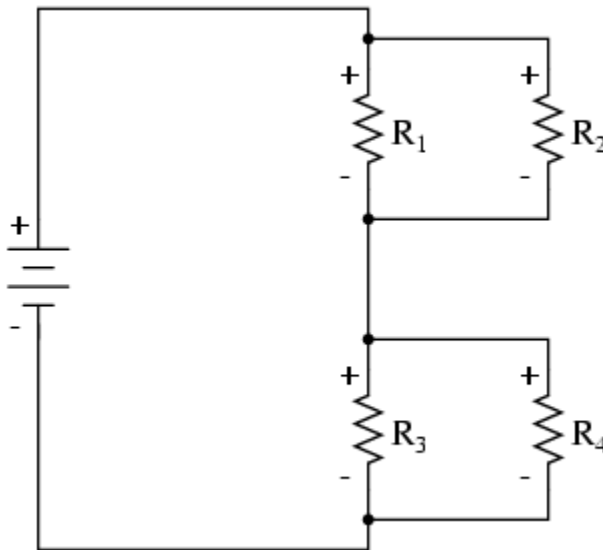
Opens and shorts alike, if occurring in a circuit, result in an overall change in the equivalent resistance. This can cause undesirable effects in other parts of the circuit due to the corresponding change in the total current flow. A short usually causes components to fail in a circuit which is not 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 in series 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.



### ***Predictive Analysis of Series-Parallel Circuits***

Through an understanding of how series, parallel, and series-parallel circuits work, a competent troubleshooter will have an understanding of how a specific failure will affect a circuit without the need to perform arithmetic. Rather, the technician can deduce the failure by observation and reasoning. In the following example, we will work backwards from a failure to show how the other components are affected.



**Figure 13: Analysis of a series-parallel circuit.**

In Figure 13, R<sub>3</sub> and R<sub>4</sub> are in parallel with one another and in series with R<sub>1</sub> and R<sub>2</sub>, which are also in parallel in with one another. This can be written symbolically as: (R<sub>3</sub>//R<sub>4</sub>)(R<sub>1</sub>//R<sub>2</sub>), where the “//” symbol indicates “in parallel.”

In previous modules, tables were used to keep tabs on all the calculated values. However, this time, they will be used to keep tabs on how each component measurement reacts to the fault.

	R <sub>1</sub>	R <sub>2</sub>	R <sub>3</sub>	R <sub>4</sub>	R <sub>1</sub> // R <sub>2</sub>	R <sub>3</sub> // R <sub>4</sub>	Total	
E								Volts
I								Amps
R								Ohms

**Figure 14: Empty Table**

Let it be supposed that  $R_2$  shorted. Assume at this time that all other components maintain their ohmic value:

	$R_1$	$R_2$	$R_3$	$R_4$	$R_1 // R_2$	$R_3 // R_4$	Total	
E							same	Volts
I								Amps
R	same	↓	same	same				Ohms

Figure 15:  $R_2$  Shorts- resistance decreases.

Because this circuit is being analyzed based on its properties rather than on its values, symbols will be used to indicate change. If the value has not changed, the word “same” will be used. Up and down arrows will be used to indicate an increase or decrease respectively. As shown in Figure 15, due to a short in  $R_2$ , its resistance has decreased, however,  $R_1$ ,  $R_3$ ,  $R_4$  and total voltage has remained the same.

Now, working through the principles of Ohm’s law and what has been learned about series-parallel circuits, the effect of the short on  $R_2$  can be determined for the rest of the circuit. First, determine what has happened to the resistance of the parallel branches. Because neither  $R_3$  nor  $R_4$  have changed, the resistance of the  $R_3 // R_4$  branch remains the same. However, because of the resistance decrease in  $R_2$ , the resistance in the  $R_1 // R_2$  branch must decrease as well. As a result, total resistance must also decrease.

	$R_1$	$R_2$	$R_3$	$R_4$	$R_1 // R_2$	$R_3 // R_4$	Total	
E							same	Volts
I								Amps
R	same	↓	same	same	↓	same	↓	Ohms

Figure 16: Parallel branch and total resistance decrease.

Using Ohm’s law in the Total column, it can be concluded that total current must increase. Remember, Ohm’s law states that **the current in a circuit is DIRECTLY proportional to the applied voltage and INVERSELY proportional to the circuit resistance.**

	$R_1$	$R_2$	$R_3$	$R_4$	$R_1 // R_2$	$R_3 // R_4$	Total	
E							same	Volts
I							↑	Amps
R	same	↓	same	same	↓	same	↓	Ohms

Figure 17:  $I = E/R$

Because the total resistance is the result of  $R_1//R_2$  and  $R_3//R_4$  in series, the total current will be the same in each of the parallel branches. Therefore, because of the increase in total current due to the failure of  $R_2$ , the current through the parallel branches must also increase:

	$R_1$	$R_2$	$R_3$	$R_4$	$R_1 // R_2$	$R_3 // R_4$	Total	
E							same	Volts
I					↑	↑	↑	Amps
R	same	↓	same	same	↓	same	↓	Ohms

Figure 18: Current increases in the branches

Once again, through understanding of Ohm’s law, we can predict how the branch of  $R_3//R_4$  will respond to the increased current. With no change in resistance and increase in current, the reaction will be an increase in voltage. However, the response of  $R_1//R_2$  is a bit less obvious. The table in Figure 18 shows that there is a decrease in resistance and an increase in current. Ohm’s law will not help with this, but if you recall the rules about voltage in a series circuit, you will know that because  $R_1//R_2$  and  $R_3//R_4$  are in series with one another, they share a common voltage. As total voltage has remained the same, but the voltage for the parallel branch  $R_3//R_4$  has increased, it is logical that the voltage for the parallel branch  $R_1//R_2$  has decreased:

	$R_1$	$R_2$	$R_3$	$R_4$	$R_1 // R_2$	$R_3 // R_4$	Total	
E					↓	↑	same	Volts
I					↑	↑	↑	Amps
R	same	↓	same	same	↓	same	↓	Ohms

Figure 19: Voltage in series is additive

Because resistors in parallel share voltage, any changes in that shared voltage will affect the individual resistors in the same fashion:

	$R_1$	$R_2$	$R_3$	$R_4$	$R_1 // R_2$	$R_3 // R_4$	Total	
E	↓	↓	↑	↑	↓	↑	same	Volts
I					↑	↑	↑	Amps
R	same	↓	same	same	↓	same	↓	Ohms

Figure 20: Voltage changes in the resistors

The application of Ohm's law to those resistors where the resistance has remained unchanged will indicate the change in current:

	$R_1$	$R_2$	$R_3$	$R_4$	$R_1 // R_2$	$R_3 // R_4$	Total	
E	↓	↓	↑	↑	↓	↑	same	Volts
I	↓		↑	↑	↑	↑	↑	Amps
R	same	↓	same	same	↓	same	↓	Ohms

Figure 21: Ohm's Law Again

All that remains now is the current change as a result of  $R_2$  being shorted. The rules for series and parallel circuits regarding current are as follows:

- The same current flows through each part of a **series circuit**.
- The total current of a **parallel circuit** is equal to the sum of the individual branch currents of the circuit.

With these rules in mind, examine the row for current.

- $R_1 // R_2$  and  $R_3 // R_4$  are parallel branches in series, therefore they share a common current
- $R_1 // R_2$  is a parallel branch that divides the common current between  $R_1$  and  $R_2$ .
- $R_3 // R_4$  is a parallel branch that divides the common current between  $R_3$  and  $R_4$ .

Therefore, because the total current (common current) has increased, then there will be an increase in the current for the parallel branches. In examining the parallel branch for  $R_3 // R_4$ ,

the increase is shared by both resistors. However, in examining the parallel branch of  $R_1//R_2$ , even though there is an increase in the branch current, there is a decrease in the current flowing  $R_2$ . Therefore,  $R_1$  must have increased:

	$R_1$	$R_2$	$R_3$	$R_4$	$R_1 // R_2$	$R_3 // R_4$	Total	
E	↓	↓	↑	↑	↓	↑	same	Volts
I	↓	↑	↑	↑	↑	↑	↑	Amps
R	same	↓	same	same	↓	same	↓	Ohms

**Figure 22: Final Analysis**

While this process seems to be drawn out and complicated, in reality the actual process can be performed quickly for the practiced technician. The important thing to understand is that this predictive process differs little from the quantitative process. In both, you start with the known values and then proceed to determine total voltage, current, and/or resistance (depending on known values). Then, using Ohm's law (and Kirchhoff's voltage and current laws) as well as the rules for series and parallel circuits, the unknowns can be determined. The power of this method is that it works in reverse. If you do not know what the fault is, you can use the same process to isolate the area where the fault is occurring.

A few general rules can be memorized to assist and/or to check your progress when proceeding with such an analysis:

- For any single component failure (open or shorted), the total resistance will always change in the same direction (either increase or decrease) as the resistance change of the failed component.
  - When a component fails shorted, its resistance always decreases.
    - The current through it will increase, and the voltage across it may drop
  - When a component fails open, its resistance always increases.
    - The current through that component will decrease to zero, because it is an incomplete electrical path (no continuity). This may result in an increase of voltage across it.

### ***Knowledge Check***

1. 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?
2. 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?
3. If one branch of a parallel network is shorted, what portion of circuit current flows through the remaining branches?
4. If an open occurs in a series portion of a circuit, what is the effect on (a) total resistance, and (b) total current?
  - a. (a) Decreases to zero      (b) Becomes infinite
  - b. (a) Decreases to zero      (b) Decreases to zero
  - c. (a) Becomes infinite      (b) Becomes infinite
  - d. (a) Becomes infinite      (b) Decreases to zero
5. If an open occurs in a parallel branch of a circuit, what is the effect on (a) total resistance, and (b) total current?
  - a. (a) Increases      (b) decreases
  - b. (a) Increases      (b) increases
  - c. (a) Decreases      (b) decreases
  - d. (a) Decreases      (b) increases
6. If a short circuit occurs in a series portion of a circuit, what is the effect on (a) total resistance, and (b) total current?
  - a. (a) Increases      (b) decreases
  - b. (a) Increases      (b) increases
  - c. (a) Decreases      (b) decreases
  - d. (a) Decreases      (b) increases

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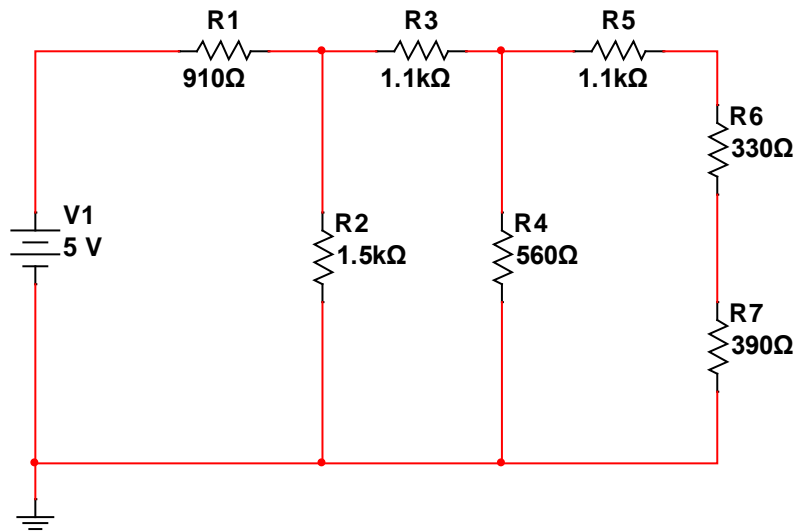
7. If a short circuit occurs in a parallel branch of a circuit, what is the effect in (a) total resistance, and (b) total current?
- a. (a) Increases      (b) decreases
  - b. (a) Increases      (b) increases
  - c. (a) Decreases      (b) decreases
  - d. (a) Decreases      (b) increases
8. If one branch of a parallel network shorts, what portion of the circuit current, if any, will flow through the remaining branches?
- a. An amount determined by the combined resistance of the remaining branches
  - b. All
  - c. One-half
  - d. None

## 1: Series-Parallel Circuit (Multisim)

### Components & Equipment Needed

- Multisim Circuit Design Suite
- Multisim file: S-P circuit.ms12

### Circuit Diagram



Circuit 1: Series-Parallel Circuit Lab 1

### Procedure

- Step 1:** Using Multisim, build the circuit shown in the schematic.
- Step 2:** Take measurements and perform calculations as required in the table below.
- Step 3:** Open the Multisim file labeled S-P circuit.ms12 in the Canvas module for Series-Parallel circuits.
- Step 4:** Take measurements and perform calculations as required in the table below.



**Tables for Series-Parallel Circuits Lab 1**

	Multisim Value	File S-P circuit.ms12 value	% Difference
$V_{R1}$			
$V_{R2}$			
$V_{R3}$			
$V_{R4}$			
$V_{R5}$			
$V_{R6}$			
$V_{R7}$			
$I_{R2}$			
$I_{R4}$			
$I_{R7}$			
$I_{Total}$			
$R_T$			

**Table 1: Series-Parallel Circuits Lab 1**

***Observations & Conclusions***

In your lab report, include your results from Table 1 as well as any observations or conclusions you may have made during this exercise.

Answer following questions in your lab report:

1. What is the faulty component and what is the fault? Please explain.
2. In the table above there is no space to record  $I_{R1}$ ,  $I_{R3}$ ,  $I_{R5}$ , or  $I_{R6}$ . Why do you think this is?

## 2: Series-Parallel Circuit (Breadboard)

### *Components & Equipment Needed*

- Breadboard
- Jumper Wires
- Resistors: 330  $\Omega$ , 390  $\Omega$ , 560  $\Omega$ , 910  $\Omega$ , 1.1 k $\Omega$  (2), 1.5 k $\Omega$
- Circuit 1, from Series-Parallel Circuits Lab 1
- DC Power Supply

### *Procedure*

- Step 1:** Build the schematic shown in Circuit 1.
- Step 2:** Take measurements and perform calculations as required in the table below.
- Step 3:** Simulate an open circuit by removing R4.
- Step 4:** Take measurements and perform calculations as required in the table below.
- Step 5:** Simulate a short circuit by replacing R4 with a jumper.
- Step 6:** Take measurements and perform calculations as required in the table below.

### *Tables for Series-Parallel Circuits Lab 2*

	Breadboard Values	R4 Open	R4 Short
$V_{R1}$			
$V_{R2}$			
$V_{R3}$			
$V_{R4}$			
$V_{R5}$			
$V_{R6}$			
$V_{R7}$			
$I_{R2}$			
$I_{R4}$			
$I_{R7}$			
$I_{Total}$			
$R_T$			

**Table 2: Series-Parallel Circuits Lab 2**

### ***Observations & Conclusions***

In your lab report, include your results from Table 2 as well as any observations or conclusions you may have made during this exercise.

Answer following question in your lab report:

1. Do the values for R4 Open and R4 Short match the values you expected? Explain.

## Answers to Knowledge Checks

### *Practice Circuit Problem*

9. Refer to Figure 5(A). If the following resistors were replaced with the values indicated:  $R_1 = 900 \Omega$ ,  $R_3 = 1 \text{ k}\Omega$ , what is the total power in the circuit? What is  $E_{R2}$ ?

**A.  $P_T = 60 \text{ W}$ ,  $E_{R2} = 10 \text{ V}$**

10. What is the value of the total resistance (Figure 6)?

- a.  $3.6\Omega$
- b.  $15\Omega$
- c.  $34\Omega$
- d.  $40\Omega$

11. What is the total power used in the circuit (Figure 6)?

- a. 1.  $22.5 \text{ W}$
- b. 2.  $26.5 \text{ W}$
- c. 3.  $60.0 \text{ W}$
- d. 4.  $250.0 \text{ W}$

12. What is the total voltage drop across  $R_3$  (Figure 6)?

- a.  $8 \text{ V}$
- b.  $12 \text{ V}$
- c.  $18 \text{ V}$
- d.  $30 \text{ V}$

13. Interactive circuit analysis from Wisc-Online.com

- a. [Series- Parallel Circuit Analysis Practice Problems – Circuit 2](#)
- b. [Series-Parallel Circuit Analysis Practice Problems – Circuit 5](#)
- c. [Series-Parallel Circuit Analysis Practice Problems – Circuit 6](#)

### ***Redrawing Circuits for Clarity***

1. 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  $R_T$ .)

**A.  $4 \Omega$**

### ***Troubleshooting Series-Parallel Circuits***

1. 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?

**A. (a) Total resistance increases, total current decreases (b) Total resistance becomes infinite, total current is equal to zero**

2. 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?

**A. (a) Total resistance decreases, total current increases (b) Total resistance decreases, total current increases.**

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

**A. None**

4. If an open occurs in a series portion of a circuit, what is the effect on (a) total resistance, and (b) total current?

A. a) Decreases to zero      (b) Becomes infinite  
B. (a) Decreases to zero      (b) Decreases to zero  
C. (a) Becomes infinite      (b) Becomes infinite  
D. (a) Becomes infinite      (b) Decreases to zero

5. If an open occurs in a parallel branch of a circuit, what is the effect on (a) total resistance, and (b) total current?

A. (a) Increases      (b) decreases  
B. (a) Increases      (b) increases  
C. (a) Decreases      (b) decreases  
D. (a) Decreases      (b) increases

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6. If a short circuit occurs in a series portion of a circuit, what is the effect on (a) total resistance, and (b) total current?
- A. (a) Increases      (b) decreases
  - B. (a) Increases      (b) increases
  - C. (a) Decreases     (b) decreases
  - D. (a) Decreases     (b) increases
7. If a short circuit occurs in a parallel branch of a circuit, what is the effect in (a) total resistance, and (b) total current?
- A. (a) Increases      (b) decreases
  - B. (a) Increases      (b) increases
  - C. (a) Decreases     (b) decreases
  - D. (a) Decreases     (b) increases
8. If one branch of a parallel network shorts, what portion of the circuit current, if any, will flow through the remaining branches?
- A. An amount determined by the combined resistance of the remaining branches
  - B. All
  - C. One-half
  - D. None

## **Additional Resources**

### ***Physics Resources***

**Georgia State University – HyperPhysics**

<http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>

### ***Video Resources***

**Khan Academy**

Circuits (part 3): <https://www.khanacademy.org/science/physics/electricity-and-magnetism/v/circuits--part-3>

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