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Excerpt from

Circuit Analysis and Ohm's Law

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Preview

The following is a sample excerpt from a study unit converted into the Adobe Acrobat format. A sample online exam is available for this excerpt.

The sample text, which is from the Electronics Technology program, introduces the concept of circuit analysis, one of the most fundamental jobs of an electrician or electronics technician. With the knowledge of how voltage, current, and resistance are related in a circuit, a person can easily learn to troubleshoot any circuit quickly and efficiently. This excerpt of the study unit focuses on circuit resistance.

After reading through the following material, feel free to take the sample exam based on this excerpt.

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CALCULATING CIRCUIT RESISTANCE

Introduction

Circuit analysis is one of the most important tasks of an electrician or electronics technician. In order to troubleshoot circuits and electrical devices, you must clearly understand how voltage, current, and resistance are related in circuits. With this knowledge, you can perform calculations that will provide you with important information about a given circuit. Then, you'll be able to quickly and easily locate the source of trouble in a faulty circuit.

Let's take a moment now to review some important topics. Remember that current is the flow of electric charge in a circuit. The amount of electric current flowing through a circuit is called *amperage.* One ampere of current is equal to the charge of 6,240,000,000,000,000,000 electrons flowing past a given point in a circuit per second. Note that in this definition of ampere, it doesn't matter which direction the electrons are flowing in.

There are two theories of electric current flow that are used to describe the movement of electrons in a circuit. You should be aware of both theories, since you'll see both of them referred to in textbooks and technical manuals. In the *electron theory* of current flow, electrons are said to flow from the negative point of a circuit to the positive point. In contrast, in the *conventional theory* of current flow, current is said to flow from the positive point of a circuit to the negative point.

Why are there two theories of current flow, and which is correct? The answer is that *both* theories are used in the study and application of electricity. The conventional theory is older and is based on the assumption that electric current flows from the positive point of a circuit to the negative point. In later years, scientists determined that electrons actually flow from the negative point of a circuit to the positive. Thus, the newer electron theory is the correct way to explain current flow.

However, the conventional theory is still used in some circles. One reason for this is that many of the standard rules of electricity were developed by scientists who used the conventional theory. Some reference books, manuals, and text books still refer to the conventional theory, so you should be familar with it. The conventional theory is also used to explain the rules of magnetism and the electrical forces produced in motors and generators.

One good example of the conventional theory in practice is an everyday car battery. In a car battery, the positive battery terminal is considered to be the "hot" terminal and is therefore painted red. According to the electron theory, the negative terminal is actually the source of electron flow. However, it would be too confusing to change the standards of battery production to adapt to a new theory of current flow! Therefore, the conventional theory continues to be used when referring to batteries.

For most practical purposes, all you need to know is that current flows out of a power source, flows through a circuit load, and then returns to the power source. It doesn't really matter in which direction the current flows. However, you should be aware of the two theories of current flow and what they mean. For our purposes in this study unit, when we talk about circuits, we'll use the electron theory to describe current flow. In addition, all our electrical diagrams are drawn using the electron or negative-to-positive standard. This is because most of the actual circuit diagrams you'll see in your work are drawn according to the electron theory.

Circuit Basics

Most DC circuits contain three basic parts: a power source, conductors, and a resistance. Resistance in a circuit may come from heaters, motors, relay coils, lights, or any other electrical devices. However, for instructional purposes, all the circuit examples in this text will contain resistors.

Now, let's briefly review the difference between a series and a parallel circuit. In a series circuit, components are connected *end-to-end.* A typical series circuit is shown in Figure 1. In this circuit, three resistors (R_1, R_2, and R_3) are connected end-to-end, and power is supplied by a battery. Current leaving the negative battery terminal will flow through R_1, R_2, and R_3, and back to the positive battery terminal. Because the components in this circuit are connected end-to-end, if any connection between the components were to break or open, the entire circuit would stop functioning.

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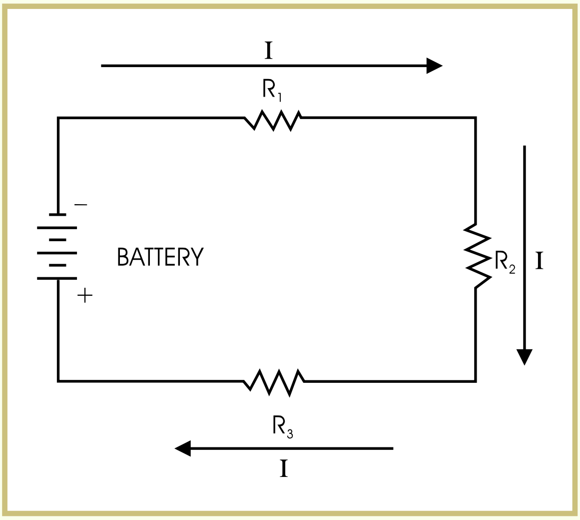


FIGURE 1—A typical series circuit has its components connected end-to-end. All of the circuit current flows through each of the circuit components.

In contrast, a parallel circuit is connected much differently. In a parallel circuit (Figure 2), the components are connected *across* each other. Current leaves the negative battery terminal and then splits into three different circuit paths. Some of the current flows through R_1, some through R_2, and the remainder through R_3. The current then flows through the conductors back to the positive battery terminal. In a parallel circuit, if one circuit path is broken or opened, current continues to flow through the other paths, and part of the circuit keeps working.

In a parallel circuit, the amount of current that flows through each resistor is related to the values of the resistors. If all three resistors have exactly the same value, then the current through each resistor will be the same. If one of the resistors is higher in value than the other two resistors, less current will flow through that resistor.

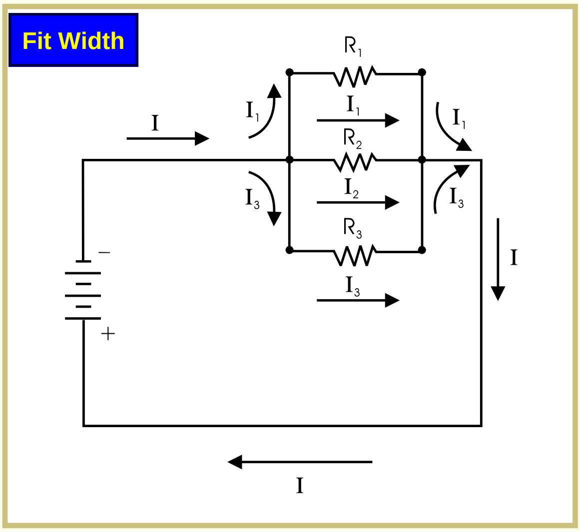


FIGURE 2—The current in this parallel circuit (I) flows from the battery and then separates onto three circuit paths (I_1, I_2 and I_3).

Calculating Resistance in Series Circuits

Series circuits are very simple circuits. Therefore, the process of calculating the total resistance of a series circuit is very simple. To calculate the total resistance of a series circuit, simply add the values of all the resistors in the circuit.

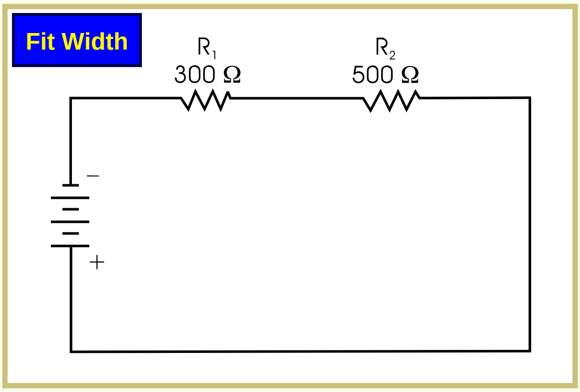
Let's begin by looking at a simple two-resistor circuit (Figure 3). In this figure, a 300 Ω (ohm) resistor (R_1) and a 500 Ω resistor (R_2) are connected in series. The total value of resistance (R_T) is equal to the sum of the resistors. The resistance is calculated as follows:

$R_T = R_1 + R_2$ Set up the problem.

$R_T = 300\ \Omega + 500\ \Omega$ Add the values of R_1 and R_2 (300 = 500 + 800).

$R_T = 800\ \Omega$ *Answer:* The total resistance is 800 Ω.

FIGURE 3—To calculate the total resistance in this series circuit, simply add the values of the two resistors.



This same addition rule applies no matter how many resistors are connected in series. For example, look at the circuit in Figure 4. Here, five resistors are connected in series. The total resistance in this circuit would be calculated as follows:

$R_T = R_1 + R_2 + R_3 + R_4 + R_5$ — Set up the problem.

$R_T = 1{,}000\ \Omega + 2{,}000\ \Omega + 100\ \Omega + 100\ \Omega + 60\ \Omega$ — Add the resistor values (1,000 + 2,000 + 100 + 100 + 60 = 3,260).

$R_T = 3{,}260\ \Omega$ — *Answer:* The total resistance is 3,260 Ω.

In summary, note that in a series circuit, the total circuit resistance will always be greater than the value of any one resistor.

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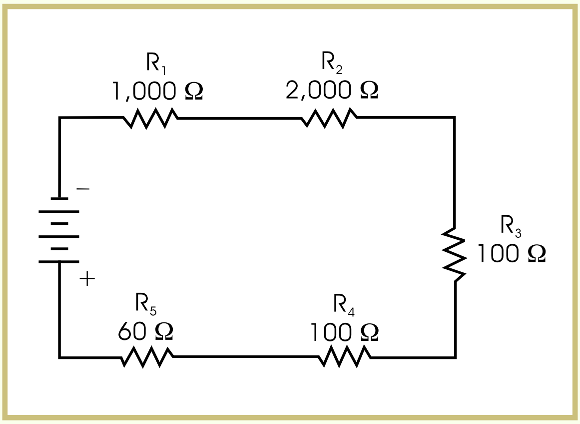


FIGURE 4—In this five-resistor circuit, the total resistance can be found by adding the values of the five resistors.

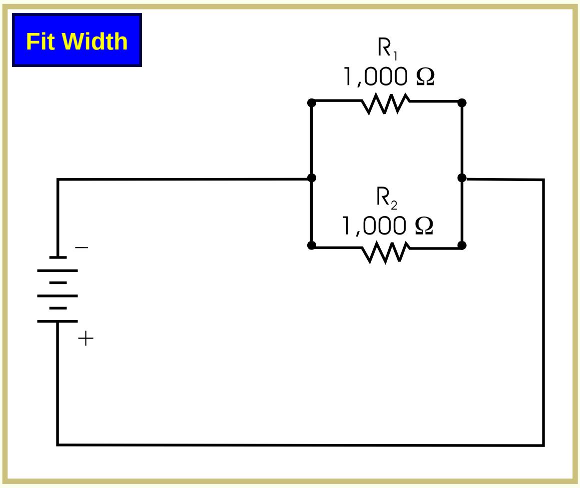
Calculating Resistance in Parallel Circuits

It's a little more difficult to calculate the total resistance in a parallel circuit. There are several ways in which you can calculate resistance in parallel circuits, and you should be familiar with all of them. The method you use in a particular situation will depend on the values of the resistors in the given circuit. We'll learn each of these methods by looking at some specific circuit examples.

First, if a parallel circuit contains resistors of equal value, the total circuit resistance will be equal to a *fraction of the value of one resistor*. So, if a parallel circuit contains two equal resistors, then the total circuit resistance is equal to one-half the value of either resistor. If the circuit contains three equal resistors, the total circuit resistance is equal to one-third of the value of one resistor. If the circuit contains four equal resistors, the total circuit resistance is equal to one-fourth the value of one resistor, and so on.

Figure 5 shows a circuit containing two 1,000 Ω resistors connected in parallel. The total resistance in this circuit is equal to one-half of 1,000 (that is, 1,000 ÷ 2). Therefore, the total circuit resistance is 500 Ω.

FIGURE 5—Since both parallel resistors are of the same value, the total resistance is equal to one-half the value of either resistor.



In another example, if a circuit contains four 1,000 Ω resistors connected in parallel, the total circuit resistance is equal to one-fourth of 1,000 (1,000 ÷ 4). Therefore, the total circuit resistance is 250 Ω.

Now, let's look at a different type of problem. If two resistors with *different values* are connected in parallel, you'll need to use a different method to calculate the total circuit resistance. To find the total resistance in such a circuit, use the following formula:

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

Figure 6 shows a 60 Ω resistor (R_1) and a 20 Ω resistor (R_2) connected in parallel. Let's find the total resistance in this circuit.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$ Write the formula.

$$R_T = \frac{60\ \Omega \times 20\ \Omega}{60\ \Omega + 20\ \Omega}$$ Substitute 60 Ω for R_1 and 20 Ω for R_2.

$$R_T = \frac{60 \times 20}{60 + 20}$$ Multiply ($60 \times 20 = 1{,}200$). Add ($60 + 20 = 80$).

$$R_T = \frac{1{,}200}{80}$$ Divide ($1{,}200 \div 80 = 15$).

$$R_T = 15\ \Omega$$ *Answer:* The total resistance of this circuit is 15 Ω.

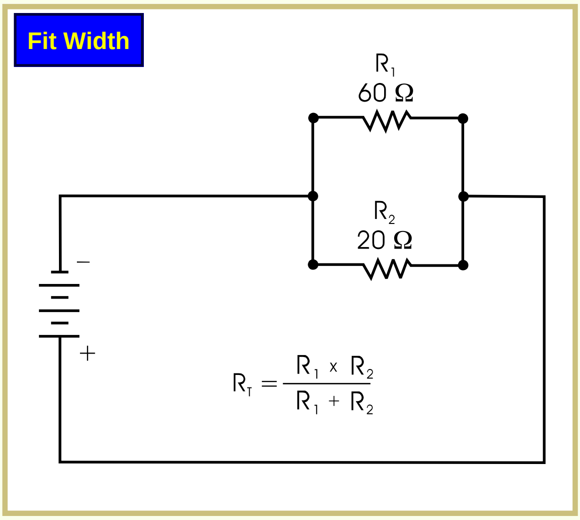


FIGURE 6—This parallel circuit contains two resistors with different values. You must use the formula shown to calculate the total resistance.

Note that the total resistance of a parallel circuit is always lower than the lowest value of any one resistor in the circuit.

Now, let's look at another example problem. Suppose a circuit contains a 1,000 Ω resistor (R_1) and a 10 Ω resistor (R_2) connected in parallel. Use the formula to calculate the total resistance of the circuit.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$ Write the formula.

$$R_T = \frac{1{,}000\ \Omega \times 10\ \Omega}{1{,}000\ \Omega + 10\ \Omega}$$ Substitute 1,000 Ω for R_1 and 10 Ω for R_2.

$$R_T = \frac{1{,}000 \times 10}{1{,}000 + 10}$$ Multiply ($1{,}000 \times 10 = 10{,}000$). Add ($1{,}000 + 10 = 1{,}010$).

$$R_T = \frac{10{,}000}{1{,}010}$$ Divide ($10{,}000 \div 1{,}010 = 9.9$).

$$R_T = 9.9\ \Omega$$ *Answer:* The total circuit resistance is 9.9 Ω (rounded).

Note that the resistor with the lowest value in this circuit was R_2 (10 Ω), and the total resistance of the circuit is *less than* 10 Ω.

In this circuit, most of the current will flow through R_2 since it has such a low resistance value. Very little current will flow through R_1 since its resistance is so large compared to that of R_2.

Now, let's look at a parallel circuit containing three resistors with different values (Figure 7). There are two methods of calculating the total resistance in such a circuit.

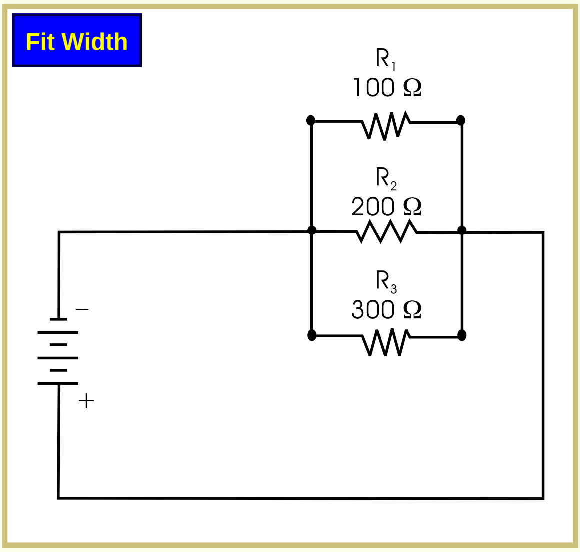


FIGURE 7—This circuit contains these resistors connected in parallel.

As shown, the values of the three resistors are 100 Ω, 200 Ω, and 300 Ω. To calculate the total resistance, first use the formula to calculate the total resistance of R_1 and R_2. Then, use that value and the value of R_3 to calculate the total circuit resistance.

$$R_{P1} = \frac{R_1 \times R_2}{R_1 + R_2}$$

Write the formula. The abbreviation R_{P1} stands for the total resistance of the first two resistors.

$$R_{P1} = \frac{100\ \Omega \times 200\ \Omega}{100\ \Omega + 200\ \Omega}$$

Substitute 100 Ω for R_1 and 200 Ω for R_2.

$$R_{P1} = \frac{100 \times 200}{100 + 200}$$

Multiply ($100 \times 200 = 20{,}000$).
Add ($100 + 200 = 300$).

$$R_{P1} = \frac{20{,}000}{300}$$

Divide ($20{,}000 \div 300 = 66.67$).

$$R_{P1} = 66.67\ \Omega$$

Answer: The total resistance of the first two resistors is 66.67 Ω (rounded).

We can now alter Figure 7 to include this value (66.67 Ω) in place of R_1 and R_2. Figure 8 shows the updated circuit diagram. The circuit now contains two resistors connected in parallel.

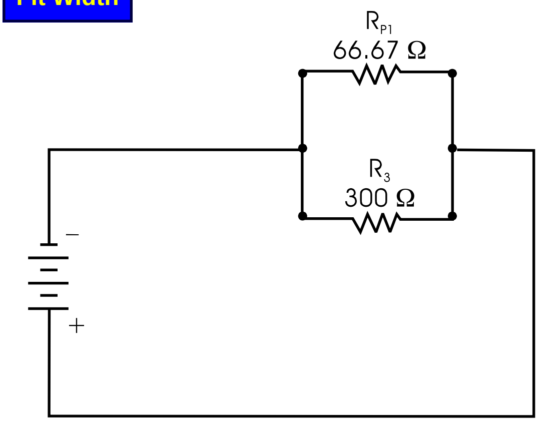


FIGURE 8—In this updated version of the circuit diagram in Figure 7, R_{P_1} is used in place of R_1 and R_2.

Now, use the value 66.67 Ω and the value of the third resistor to find the total circuit resistance.

$$R_T = \frac{R_{P_1} \times R_3}{R_{P_1} + R_3}$$ Write the formula.

$$R_T = \frac{66.67\ \Omega \times 300\ \Omega}{66.67\ \Omega + 300\ \Omega}$$ Substitute 66.67 Ω for R_{P1} and 300 Ω for R_3.

$$R_T = \frac{66.67 \times 300}{66.67 + 300}$$ Multiply ($66.67 \times 300 = 20{,}001$). Add ($66.67 + 300 = 366.67$).

$$R_T = \frac{20{,}001}{366.67}$$ Divide ($20{,}001 \div 366.67 = 54.55$).

$$R_T = 54.55\ \Omega$$ *Answer:* The total resistance of this circuit is 54.55 Ω (rounded).

Note that the total resistance of this circuit (54.55 Ω) is less than the lowest value of any one resistor (100 Ω).

Another method you can use to find the total resistance of a parallel circuit is the *reciprocal method.* Every number has a reciprocal. The reciprocal of a given number is one divided by the number. So, the reciprocal of 5 is $\frac{1}{5}$. The reciprocal of 12 is $\frac{1}{12}$.

To find the total resistance of a parallel circuit using the reciprocal method, first find the reciprocal of each resistor value. Then, add all the reciprocal values together. Finally, find the reciprocal of that value to get the total resistance.

This isn't as difficult as it sounds! Just use the following reciprocal formula to make your calculations:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Let's look at an example problem. The circuit shown in Figure 9 contains three resistors with values of 20 Ω, 40 Ω, and 50 Ω. Use the reciprocal formula to find the total circuit resistance.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Write the formula.

$$\frac{1}{R_T} = \frac{1}{20\ \Omega} + \frac{1}{40\ \Omega} + \frac{1}{50\ \Omega}$$

Substitute the values of R_1, R_2, and R_3. Divide to simplify each of the fractions. (1 ÷ 20 = 0.05; 1 ÷ 40 = 0.025; 1 ÷ 50 = 0.02).

$$\frac{1}{R_T} = 0.05 + 0.025 + 0.02$$

Add (0.05 + 0.025 + 0.02 = 0.095).

$$\frac{1}{R_T} = 0.095\ \Omega$$

The reciprocal of 0.095 Ω is $\frac{1}{0.095}$.

$$R_T = \frac{1}{0.095}$$

Divide (1 ÷ 0.095 = 10.53).

$$R_T = 10.53\ \Omega$$

Answer: The total resistance of this circuit is 10.53 Ω (rounded).

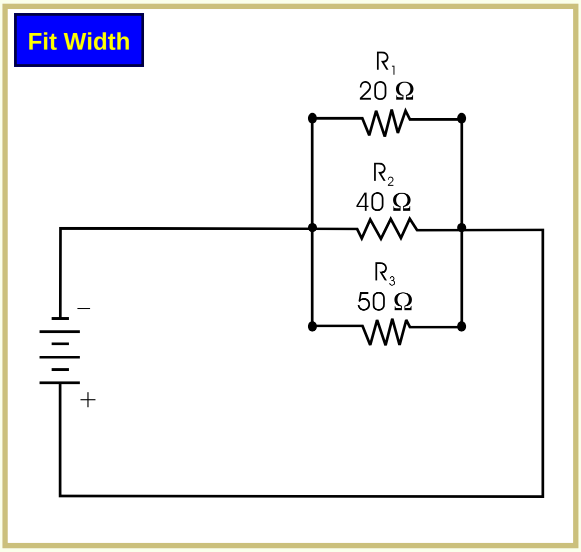


FIGURE 9—This circuit contains three resistors connected in parallel.

The reciprocal method can be used to calculate the total resistance of a circuit no matter how many resistors are connected in parallel.

Calculating Resistance in Series-Parallel Circuits

When you're working with real-life circuits, you'll find that they're not always neatly laid out in series or parallel. Often, circuits contain both series and parallel connections. This type of circuit is called a combination or series-parallel circuit. The circuit in Figure 10 contains a total of four resistors joined in both series and parallel connections.

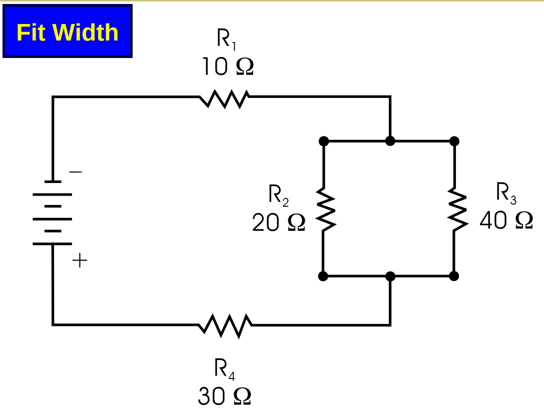


FIGURE 10—This circuit contains four resistors connected in both series and parallel arrangements.

Now, let's calculate the total resistance of the circuit shown in Figure 10. The first step is to find the resistance of the parallel portion of the circuit. This value can easily be found by using the resistance formula.

$$R_P = \frac{R_2 \times R_3}{R_2 + R_3}$$ Write the formula.

$$R_P = \frac{20\ \Omega \times 40\ \Omega}{20\ \Omega + 40\ \Omega}$$ Substitute the values of R_2 and R_3.

$$R_P = \frac{20 \times 40}{20 + 40}$$ Multiply ($20 \times 40 = 800$). Add ($20 + 40 = 60$).

$$R_P = \frac{800}{60}$$ Divide ($800 \div 60 = 13.33$).

$$R_P = 13.33\ \Omega$$ Answer: The total resistance of the parallel section of this circuit is 13.33 Ω (rounded).

Now, let's substitute this value for the parallel section in our circuit diagram. The revised diagram is shown in Figure 11. With this substitution, the circuit diagram in Figure 11 is now a simple series circuit.

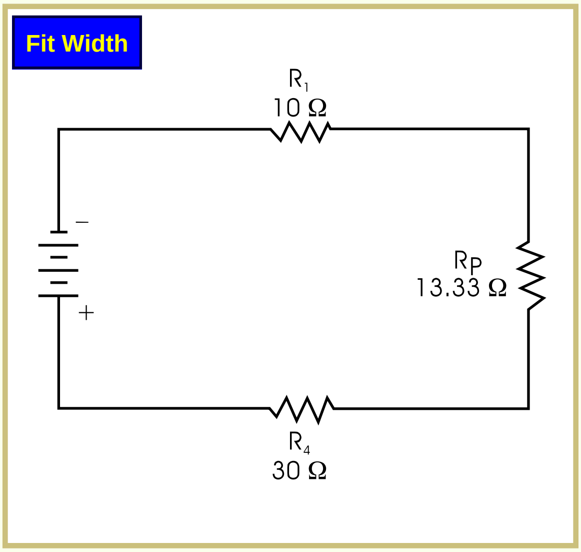


FIGURE 11—In this updated version of Figure 10, the values of R_2 and R_3 have been replaced by the value R_P.

Since you now have a series circuit, your calculations are easy to complete. Simply add the remaining resistor values together to get the total resistance for this circuit.

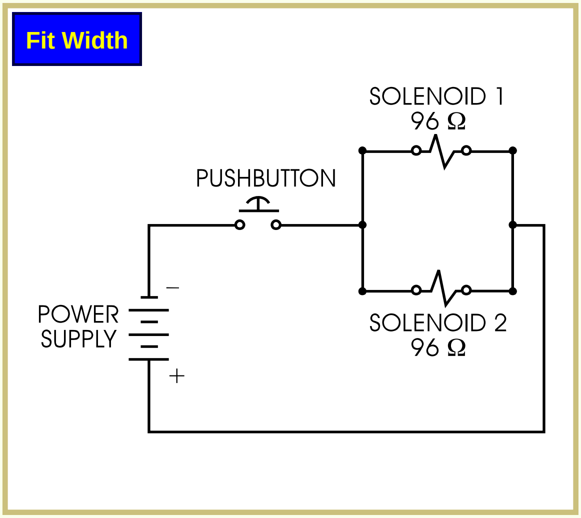
$R_T = R_1 + R_P + R_4$	Set up the problem.
$R_T = 10\ \Omega + 13.33\ \Omega + 30\ \Omega$	Substitute the values for R_1, R_P, and R_4. Add (10 + 13.33 + 30 = 53.33).
$R_T = 53.33\ \Omega$	Answer: The total resistance of this circuit is 53.33 Ω.

Practical Example

The ability to calculate total circuit resistance in series and parallel circuits is an important skill for the industrial electrician or electronics technician. This knowledge can often be used to troubleshoot a faulty machine quickly and efficiently.

For example, suppose you're working on a press that has two solenoid valves connected in parallel. The valves are activated by a pushbutton. When the machine is functioning properly, the operator presses the button, and both solenoid coils are energized. One coil lifts a shield, and the other retracts a locator. The solenoid coils each have a resistance value of 96 Ω and are connected in parallel. The circuit diagram for this machine is shown in Figure 12.

FIGURE 12—In this circuit, two solenoid coils are connected in parallel.



Now, suppose that the machine is malfunctioning. When the operator presses the button, the locator retracts, but the shield doesn't lift. This problem could be the result of an open solenoid coil or a stuck solenoid valve. How can you figure out what the problem is?

To troubleshoot this machine, use a meter to measure the resistance of the two parallel coils.

Since the two solenoids have the same resistance value, the total circuit resistance should be one-half the resistance value of one solenoid coil.

$$R_P = \frac{96\ \Omega}{2}$$ Divide the value of one resistance by 2.

$$R_T = 48\ \Omega$$ Answer: The total circuit resistance is 48 Ω.

The total circuit resistance is 48 Ω, so if you read 48 Ω on your meter, the solenoid valve is stuck. If you read 96 Ω, one of the two coils, the one for the shield, has opened causing the failure of the solenoid valve.