Parallel Circuits

OBJECTIVES:
After performing this experiment, you will be able to:
1. Demonstrate that the total resistance in a parallel circuit decreases as resistors are added.
2. Compute and measure resistance and currents in parallel circuits.
3. Explain how to troubleshoot parallel circuits.

READING:
Floyd, Principles of Electric Circuits, Sections 6–1 through 6–10

MATERIALS NEEDED:
Resistors:
- One 3.3 kΩ, one 4.7 kΩ, one 6.8 kΩ, one 10.0 kΩ
- One dc ammeter, 0–10 mA
Application Problem: One 1.0 kΩ potentiometer

SUMMARY OF THEORY:
A parallel circuit is one in which there is more than one path for current to flow. Parallel circuits can be thought of as two parallel lines, representing conductors, with a voltage source and components connected between the lines. This idea is illustrated in Figure 9–1. The source voltage appears across each component. Each path for current is called a branch. The current in any branch is dependent only on the resistance of that branch and the source voltage.

![Figure 9–1](image)

As more branches are added to a parallel circuit, the total resistance decreases. This is easy to see if you consider each added path in terms of conductance. Recall that conductance is the reciprocal of resistance. As parallel branches are added, new paths are provided for current, increasing the conductance. More total current flows in the circuit. If the total current in a circuit increases, with no change in source voltage, the total resistance must decrease according to Ohm’s law. The total conductance of a parallel circuit is the sum of the individual conductances. This can be written:

\[ G_T = G_1 + G_2 + G_3 + \cdots + G_i \]
By substituting the definition for resistance into the formula for conductance, the reciprocal formula for resistance in parallel circuits is obtained:

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

In parallel circuits, there are junctions where two or more components are connected. Figure 9–2 shows a circuit junction labeled A. Since electrical charge cannot accumulate at a point, the current flowing into the junction must be equal to the current flowing from the junction. This idea is Kirchhoff’s current law, which is stated as follows:

The sum of the currents entering a circuit junction is equal to the sum of the currents leaving the junction.

One important idea can be seen by applying Kirchhoff’s current law to a point next to the source voltage. The current leaving the source must be equal to the sum of the individual branch currents. Although Kirchhoff’s voltage law is developed in the study of series circuits and the current law is developed in the study of parallel circuits, keep in mind that both laws are applicable to any circuit.

The voltage divider rule was developed for series circuits on the premise that the same current was in all components of a series circuit. In a parallel circuit, the same voltage is across every component. By equating the $IR$ drop across each component in parallel, the current divider rule can be developed. The current divider rule has two useful forms. The first is the general equation for a parallel circuit containing several resistors, as illustrated in Figure 9–3. The general equation for the current divider is

$$I_x = \left(\frac{R_T}{R_x}\right) I_T$$

The second form of the current divider rule is applied to the special case of two resistors in parallel. The current in each of the resistors is given by

$$I_1 = \left(\frac{R_2}{R_1 + R_2}\right) I_T \quad \text{and} \quad I_2 = \left(\frac{R_1}{R_1 + R_2}\right) I_T$$
PROCEDURE:
1. Obtain the resistors listed in Table 9–1. Measure and record the value of each resistor.

2. In Table 9–2 you will tabulate the total resistance as resistors are added in parallel. (Parallel connections are indicated with two parallel lines shown between the resistors.) Enter the measured value of \( R_1 \) in the table. Then connect \( R_2 \) in parallel with \( R_1 \) and measure the total resistance, as shown in Figure 9–4. Enter the measured resistance of \( R_1 \) in parallel with \( R_2 \) in Table 9–2.

\[ \begin{array}{c}
R_1 \\
3.3 \text{ k}\Omega
\end{array} \quad \begin{array}{c}
R_2 \\
4.7 \text{ k}\Omega
\end{array} \quad \begin{array}{c}
\Omega
\end{array} \]

Figure 9–4

3. Add \( R_3 \) in parallel with \( R_1 \) and \( R_2 \). Measure the parallel resistance of all three resistors. Then add \( R_4 \) in parallel with the other resistors and repeat the measurement. Record your results in Table 9–2.

4. Complete the parallel circuit by adding the voltage source and the ammeter, as shown in Figure 9–5. Be certain that the ammeter is connected in series with the voltage source, as shown. If you are not sure, have your instructor check your circuit. Measure the total current and record it in Table 9–2.

\[ V_s = +12 \text{ V} \]

\[ \begin{array}{c}
V_s \\
+12 \text{ V}
\end{array} \quad \begin{array}{c}
R_1 \\
3.3 \text{ k}\Omega
\end{array} \quad \begin{array}{c}
R_2 \\
4.7 \text{ k}\Omega
\end{array} \quad \begin{array}{c}
R_3 \\
6.8 \text{ k}\Omega
\end{array} \quad \begin{array}{c}
R_4 \\
10.0 \text{ k}\Omega
\end{array} \quad \begin{array}{c}
A
\end{array} \]

Figure 9–5

5. Measure the voltage across each resistor. If you have correctly connected them in parallel, the voltage will be the same across each resistor and equal to the source voltage.

6. Use Ohm’s law to compute the branch current in each resistor. Use the source voltage and the measured resistances. Tabulate the computed currents in Table 9–3.

7. Using the currents computed in step 6, prove Kirchhoff’s current law for the circuit by showing that the total current is equal to the sum of the branch currents. Write your proof in the results and conclusion section of your report.

8. Simulate a burned-out (open) resistor by removing \( R_1 \) from the circuit. Measure the new total current in the circuit. Record the current in Table 9–4.
FOR FURTHER INVESTIGATION:
Kirchhoff’s current law can be applied to any junction in a circuit. The currents in this circuit were $I_1, I_2, I_3, I_4,$ and $I_7$. Apply Kirchhoff’s current law to these currents by writing the numerical value of the current entering and leaving each junction circled in Figure 9–6. Then verify that you computed the correct currents by measuring them with the ammeter. Summarize your results in your report.

![Figure 9–6](image)

APPLICATION PROBLEM:
The range of an ammeter can be greatly increased by providing a parallel path for current around the meter. The parallel resistance is termed a shunt. In order to compute the proper shunt for an ammeter, the internal resistance of the meter must be known as well as its sensitivity. The sensitivity of an ammeter is the current required to produce full-scale deflection. With sensitive meters, it is best to determine the internal meter resistance indirectly to avoid damage to the meter. The following procedure is a method to determine the internal resistance of an ammeter indirectly. The method is called the full-scale deflection method:

1. **Obtain a 10 kΩ resistor and place it in series with the ammeter.** Connect a variable power supply as shown in Figure 9–7 and slowly increase the voltage until the meter is reading full scale. *(Note: For low-resistance meters, it may be necessary to change the resistor to a lower value in order to keep the voltage at a low level.) Measure the power supply voltage at full-scale deflection.*

2. **Connect a 1.0 kΩ variable resistor in parallel with the meter,** as shown in Figure 9–8. Adjust the variable resistor until the meter reads about 40% of full scale. *(Exact reading is not critical.)*

3. **Set the power supply to exactly twice the voltage noted in step 1.** Then adjust the variable resistor until the meter reads exactly full scale. At this point the variable resistor has the same resistance as the internal resistance of the meter. Turn off the power supply and remove the variable resistor from the circuit. The variable resistor can now be measured with an ohmmeter.

![Figure 9–7](image)

![Figure 9–8](image)
For this application problem, do the following:

1. **Determine the internal resistance of the** 10 mA ammeter for this experiment using the full-scale deflection method described previously. Although a 10 mA meter is not particularly sensitive and in most cases could be measured directly with an ohmmeter, this exercise will assure you understand the method.

2. Calculate the value of a shunt resistor that can be placed in parallel with your ammeter to cause it to read 50 mA full scale. The shunt will need to pass 40 mA around the meter.

3. Set a variable resistor for the value determined in step 2 and place it in parallel with the meter. The circuit is shown in Figure 9–9. Monitor the voltage across the series resistor and adjust the power supply until 5.0 V is across it. Calculate the current leaving the supply and confirm that the meter is reading one-fifth of the circuit current. Summarize your work in your report.

![Figure 9–9](Image)