SERIES-PARALLEL CIRCUITS

5

CHAPTER OUTLINE

CHAPTER OBJECTIVES

- Identify series-parallel relationships
- Analyze series-parallel circuits
- Analyze loaded voltage dividers
- Determine the loading effect of a voltmeter on a circuit
- Analyze and apply a Wheatstone bridge
- Apply Thevenin's theorem to simplify a circuit for analysis
- Apply the maximum power transfer theorem
- Apply the superposition theorem to circuit analysis
- Troubleshoot series-parallel circuits

KEY TERMS

- Loading
- Load current
- Bleeder current
- Wheatstone bridge
- Balanced bridge
- Unbalanced bridge
- Thevenin's theorem
- Terminal equivalency
- Maximum power transfer
- Superposition

APPLICATION ASSIGNMENT PREVIEW

Your application assignment in this chapter is to evaluate a voltage-divider circuit board used in a portable power supply by applying your knowledge of loaded voltage dividers gained in this chapter as well as skills developed in previous chapters. The voltage divider in this application is designed to provide reference voltages to three different instruments that act as loads on the circuit. You will also troubleshoot the circuit board for various common faults. After studying this chapter, you should be able to complete the application assignment.

VISIT THE COMPANION WEBSITE

Study aids for this chapter are available at
http://www.prenhall.com/floyd

INTRODUCTION

Various combinations of both series and parallel resistors are often found in electronic circuits. In this chapter, examples of such series-parallel arrangements are examined and analyzed. An important circuit called the *Wheatstone bridge* is introduced, and you will learn how complex circuits can be simplified using Thevenin's theorem. The maximum power transfer theorem, used in applications where it is important for a given circuit to provide maximum power to a load, is discussed. Also, circuits with more than one voltage source are analyzed in simple steps using the superposition theorem. Troubleshooting series-parallel circuits for shorts and opens is also covered.

串并联电路

5

本章概要

本章目标

- 识别串并联关系
- 分析串并联电路
- 分析带载的分压器电路
- 求电路中电压表的负载效应
- 分析和应用惠特斯通电桥
- 用戴维南定理简化电路分析
- 应用最大功率传输定理
- 用叠加定理进行电路分析
- 串并联电路调试

核心术语

- Loading（带载）
- Load current（负载电流）
- Bleeder current（旁漏电流）
- Wheatstone bridge（惠特斯通电桥）
- Balanced bridge（平衡电桥）
- Unbalanced bridge（不平衡电桥）
- Thevenin’s theorem（戴维南定理）
- Terminal equivalency（端口等效性）
- Maximum power transfer（最大功率传输）
- Superposition（叠加）

应用型作业预告

本章的应用型作业将用这里学到的带载分压器知识和此前获得的技能来分析便携式电源中的分压器电路板。这里的分压器电路板将对三种不同的仪器（即电路的负载）提供参考电压。你还将对该电路板的不同故障进行调试。学完本章后，读者应该能够完成该作业。

访问相关网站

与本章相关的网站请参见：
http://www.prenhall.com/floyd

简介

电子电路中常见各种类型的串并联电阻。本章介绍串并联电阻电路的分析。此外还要介绍惠特斯通电桥、可简化电路分析的戴维南定理、用于给负载提供最大功率的最大功率传输定理、有多个电源时可用于分析电路的叠加定理等内容。串并联电路开路、短路故障的调试将在最后讨论。

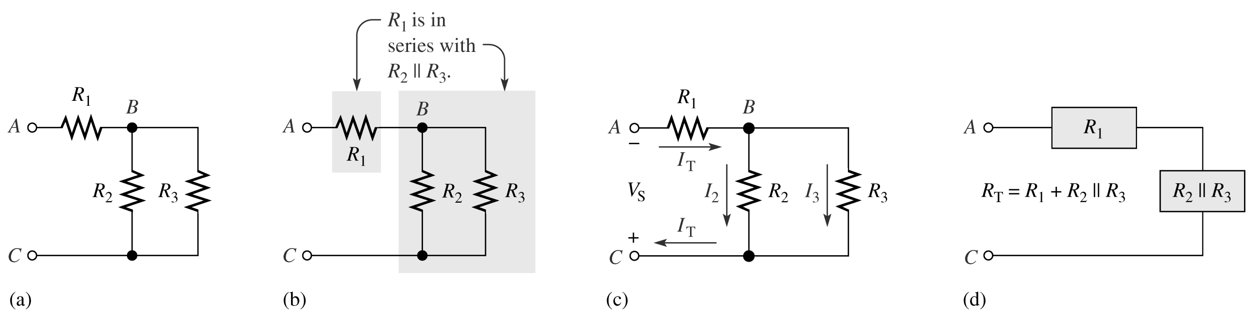
5–1 IDENTIFYING SERIES-PARALLEL RELATIONSHIPS

A series-parallel circuit consists of combinations of both series and parallel current paths. It is important to be able to identify how the components in a circuit are arranged in terms of their series and parallel relationships.

After completing this section, you should be able to

- **Identify series-parallel relationships**
  - Recognize how each resistor in a given circuit is related to the other resistors
  - Determine series and parallel relationships on a PC board

Figure 5–1(a) shows an example of a simple series-parallel combination of resistors. Notice that the resistance from *A* to *B* is R_1. The resistance from *B* to *C* is R_2 and R_3 in parallel ($R_2 \parallel R_3$) because these resistors are connected to the same pair of nodes (node *B* and node *C*). The total resistance from *A* to *C* is R_1 in series with the parallel combination of R_2 and R_3, as indicated in Figure 5–1(b).



▲ **FIGURE 5–1**

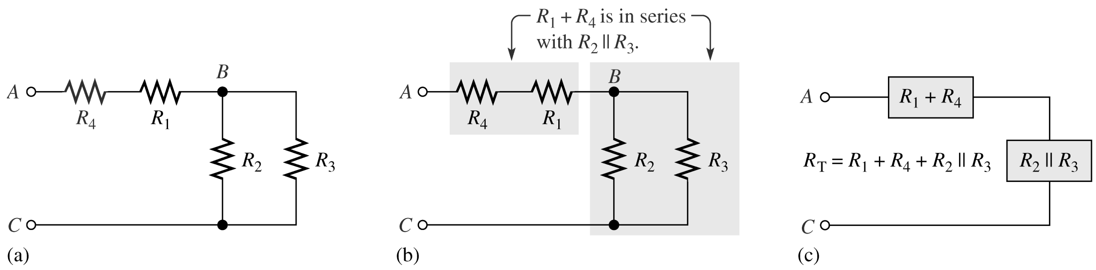
A simple series-parallel resistive circuit.

When the circuit in Figure 5–1 is connected to a voltage source as shown in part (c) the total current through R_1 divides at point *B* into the two parallel paths. These two branch currents then recombine. The total current is into the positive source terminal as shown. The resistor relationships are shown in block form in part (d).

Now, to further illustrate series-parallel relationships, let's increase the complexity of the circuit in Figure 5–1(a) step-by-step.

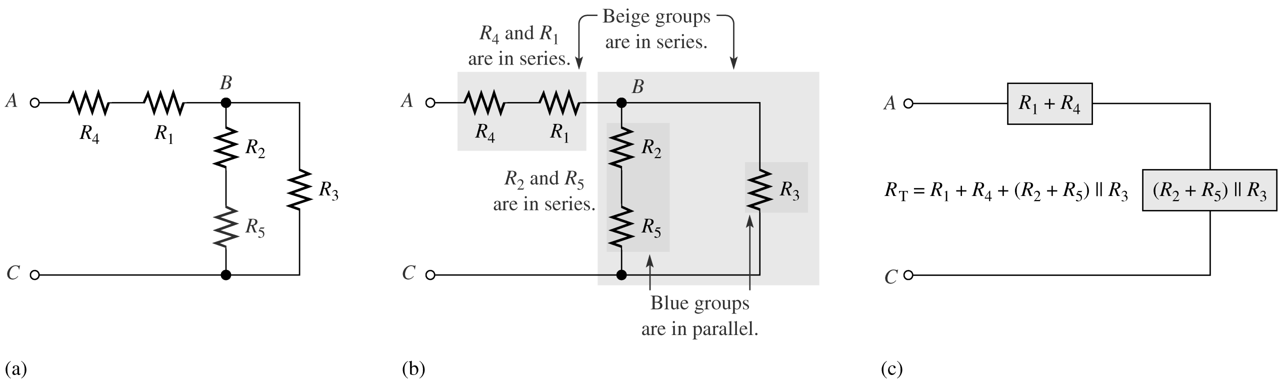
1. In Figure 5–2(a), R_4 is connected in series with R_1. The resistance between points *A* and *B* is now $R_1 + R_4$. This series combination is in series with the parallel combination of R_2 and R_3, as illustrated in Figure 5–2(b). Part (c) shows the resistor relationships in block form.
2. In Figure 5–3(a), R_5 is connected in series with R_2. The series combination of R_2 and R_5 is in parallel with R_3. This entire series-parallel combination is in series with the $R_1 + R_4$ combination, as illustrated in Figure 5–3(b). The block diagram is shown in part (c).
3. In Figure 5–4(a), R_6 is connected in parallel with the series combination of R_1 and R_4. The series-parallel combination of R_1, R_4, and R_6 is in series with the series-parallel combination of R_2, R_3, and R_5, as indicated in Figure 5–4(b). The block diagram is shown in part (c).

This icon indicates selected websites for further information on topics in this section. See the Companion Website provided with this text.



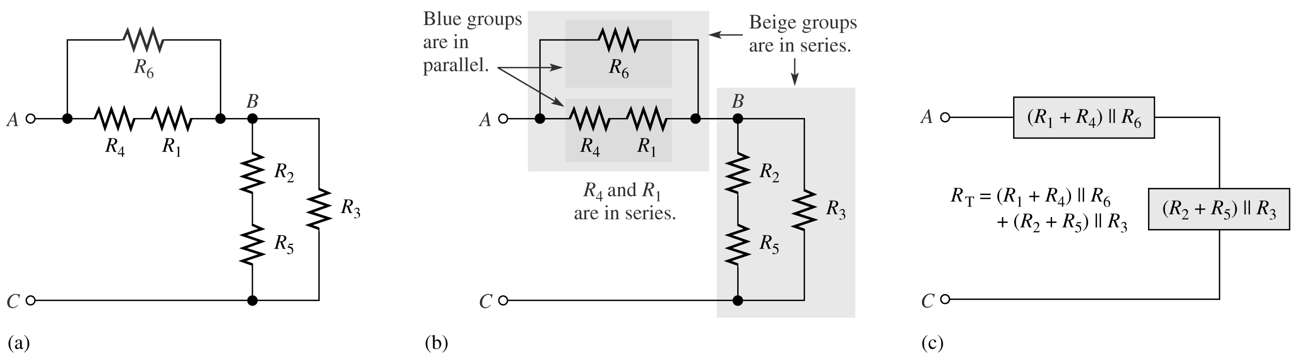
▲ **FIGURE 5–2**

R_4 is added to the circuit in series with R_1.



▲ **FIGURE 5–3**

R_5 is added to the circuit in series with R_2.



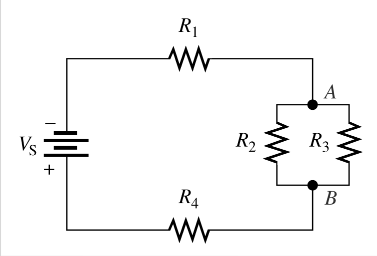
▲ **FIGURE 5–4**

R_6 is added to the circuit in parallel with the series combination of R_1 and R_4.

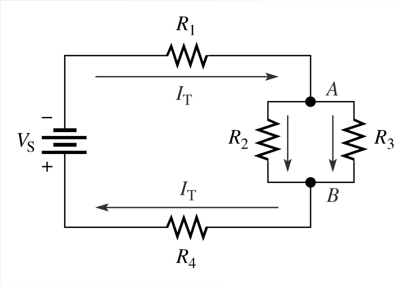
EXAMPLE 5–1 Identify the series-parallel relationships in Figure 5–5.

Solution Starting at the negative terminal of the source, follow the current paths.

1. All the current produced by the source must go through R_1, which is in series with the rest of the circuit.
2. The total current takes two paths when it gets to node A. Part of it is through R_2, and part of it is through R_3.



▲ FIGURE 5–5



▲ FIGURE 5–6

3. Resistors R_2 and R_3 are in parallel with each other because they are connected to the same pair of nodes. This parallel combination is in series with R_1.
4. At node B, the currents through R_2 and R_3 come together again into a single path. Thus, the total current is through R_4.
5. Resistor R_4 is in series with both R_1 and the parallel combination of R_2 and R_3.

The currents are shown in Figure 5–6, where I_T is the total current. In summary, R_1 and R_4 are in series with the parallel combination of R_2 and R_3.

$$R_1 + R_4 + R_2 \| R_3$$

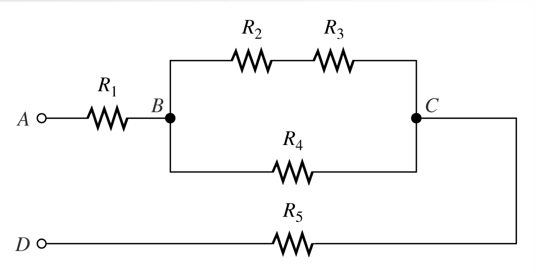
*Related Problem** If another resistor, R_5, is connected from node A to the positive side of the source in Figure 5–6, what is its relationship to the other resistors?

*Answers are at the end of the chapter.

EXAMPLE 5–2

Describe the series-parallel combination between terminals A and D in Figure 5–7.

▶ FIGURE 5–7



Solution Between nodes B and C, there are two parallel paths.

1. The lower path consists of R_4.
2. The upper path consists of a series combination of R_2 and R_3.

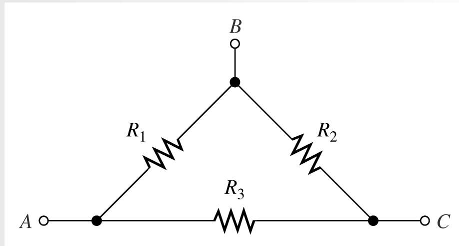
This parallel combination is in series with both R_1 and R_5. In summary, R_1 and R_5 are in series with the parallel combination of R_4 and ($R_2 + R_3$).

$$R_1 + R_5 + R_4 \| (R_2 + R_3)$$

Related Problem If a resistor is connected from node C to node D in Figure 5–7, describe its relationship in the circuit.

EXAMPLE 5–3 Describe the total resistance between each pair of terminals in Figure 5–8.

▶ FIGURE 5–8



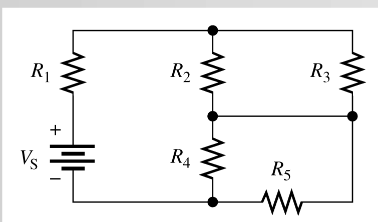
Solution

1. From A to B: R_1 is in parallel with the series combination of R_2 and R_3.
2. From A to C: R_3 is in parallel with the series combination of R_1 and R_2.
3. From B to C: R_2 is in parallel with the series combination of R_1 and R_3.

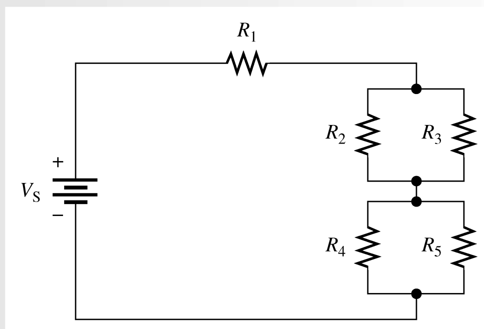
Related Problem In Figure 5–8, describe the total resistance between each terminal and an added ground if a new resistor, R_4, is connected from terminal C to ground. None of the existing resistors connect directly to the ground.

When connecting a circuit on a protoboard from a schematic, it is easier to check the circuit if the resistors and connections on the protoboard are oriented so that they approximately match the way the schematic is drawn. In some cases, it is difficult to see the series-parallel relationships on a schematic because of the way in which it is drawn. In such a situation, it helps to redraw the diagram so that the relationships become clear.

EXAMPLE 5–4 Identify the series-parallel relationships in Figure 5–9.



▲ FIGURE 5–9



▲ FIGURE 5–10

Solution The circuit schematic is redrawn in Figure 5–10 to better illustrate the series-parallel relationships. Now you can see that R_2 and R_3 are in parallel with each other and also that R_4 and R_5 are in parallel with each other. Both parallel combinations are in series with each other and with R_1.

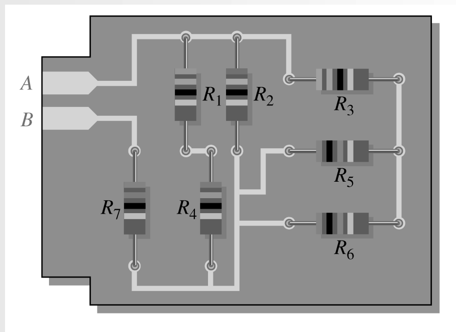
$$R_1 + R_2 \parallel R_3 + R_4 \parallel R_5$$

Related Problem If a resistor is connected from the bottom end of R_3 to the top end of R_5 in Figure 5–10, what effect does it have on the circuit? Explain.

Usually, the physical arrangement of components on a PC or protoboard bears no resemblance to the actual electrical relationships. By tracing out the circuit and rearranging the components on paper into a recognizable form, you can determine the series-parallel relationships.

EXAMPLE 5–5 Determine the relationships of the resistors on the PC board in Figure 5–11.

▶ **FIGURE 5–11**



请读者先不要往下看，自己努力从印刷电路板看出各个电阻的串并联关系。

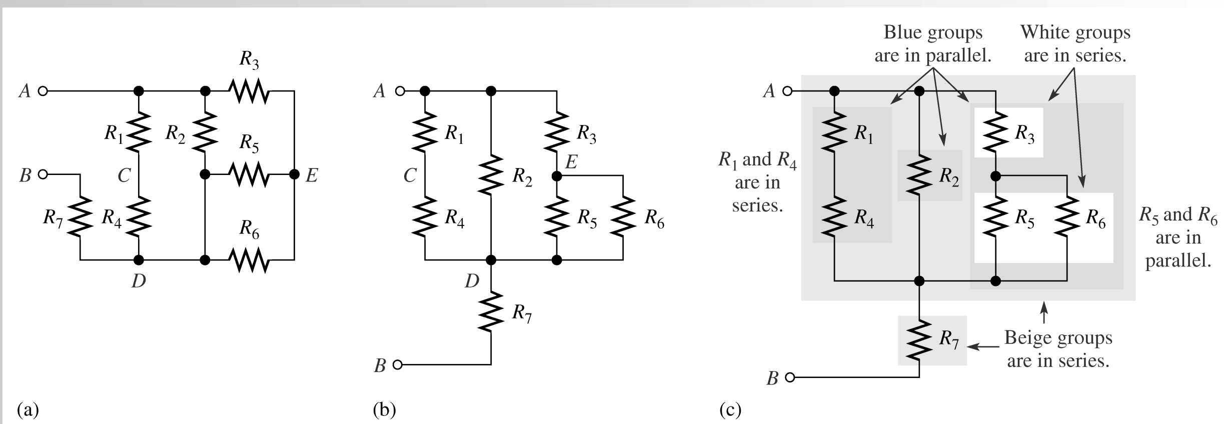
Solution In Figure 5–12(a), the schematic is drawn approximately in the same arrangement as that of the resistors on the board. In part (b), the resistors are reoriented so that the series-parallel relationships are more obvious.

Resistors R_1 and R_4 are in series, $R_1 + R_4$ is in parallel with R_2; R_5 and R_6 are in parallel, and this combination is in series with R_3.

The R_3, R_5, and R_6 series-parallel combination is in parallel with both R_2 and the $R_1 + R_4$ combination. This entire series-parallel combination is in series with R_7.

Figure 5–12(c) illustrates these relationships. Summarizing in equation form,

$$R_{AB} = (R_5 \parallel R_6 + R_3) \parallel R_2 \parallel (R_1 + R_4) + R_7$$

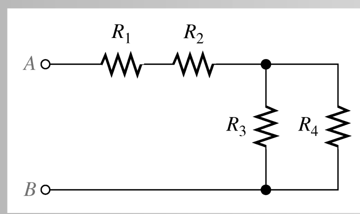


▲ **FIGURE 5–12**

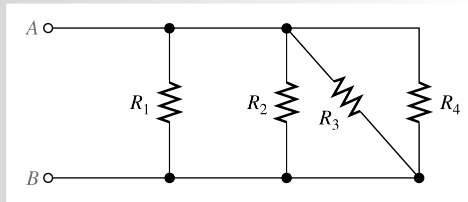
Related Problem What happens if there is an open connection between R_1 and R_4 on the printed circuit board in Figure 5–11?

SECTION 5–1 CHECKUP
Answers are at the end of the chapter.

1. A certain series-parallel circuit is described as follows: R_1 and R_2 are in parallel. This parallel combination is in series with another parallel combination of R_3 and R_4. Draw the circuit.
2. In the circuit of Figure 5–13, describe the series-parallel relationships of the resistors.
3. Which resistors are in parallel in Figure 5–14?



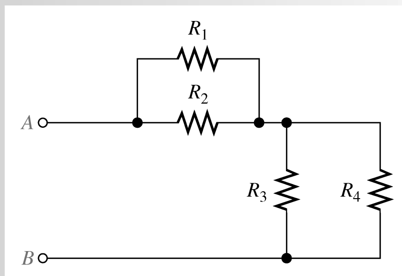
▲ FIGURE 5–13



▲ FIGURE 5–14

4. Identify the parallel resistors in Figure 5–15.
5. Are the parallel combinations in Figure 5–15 in series?

▶ FIGURE 5–15



5–2 Analysis of Series-Parallel Resistive Circuits

The analysis of series-parallel circuits can be approached in many ways, depending on what information you need and what circuit values you know. The examples in this section do not represent an exhaustive coverage, but they give you an idea of how to approach series-parallel circuit analysis.

After completing this section, you should be able to

- **Analyze series-parallel circuits**
  - Determine total resistance
  - Determine all the currents
  - Determine all the voltage drops

If you know Ohm's law, Kirchhoff's laws, the voltage-divider formula, and the current-divider formula, and if you know how to apply these laws, you can solve most resistive circuit analysis problems. The ability to recognize series and parallel combinations is, of course, essential. There is no standard "cookbook" approach that can be applied to all situations. Logical thought is the most powerful tool you can apply to problem solving.

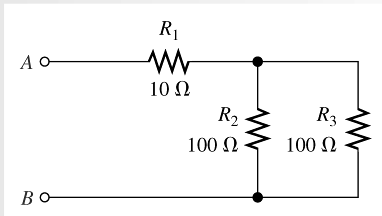
Total Resistance

In Chapter 3, you learned how to determine total series resistance. In Chapter 4, you learned how to determine total parallel resistance. To find the total resistance (R_T) of a series-parallel combination, first identify the series and parallel relationships, and then apply what you have previously learned. The following two examples illustrate the general approach.

EXAMPLE 5–6

Determine R_T between terminals A and B of the circuit in Figure 5–16.

▶ FIGURE 5–16



Solution Resistors R_2 and R_3 are in parallel, and this parallel combination is in series with R_1. First find the parallel resistance of R_2 and R_3. Since R_2 and R_3 are equal in value, divide the value by 2.

$$R_{2\|3} = \frac{R}{n} = \frac{100\ \Omega}{2} = 50\ \Omega$$

Now, since R_1 is in series with $R_{2\|3}$, add their values.

$$R_T = R_1 + R_{2\|3} = 10\ \Omega + 50\ \Omega = \mathbf{60\ \Omega}$$

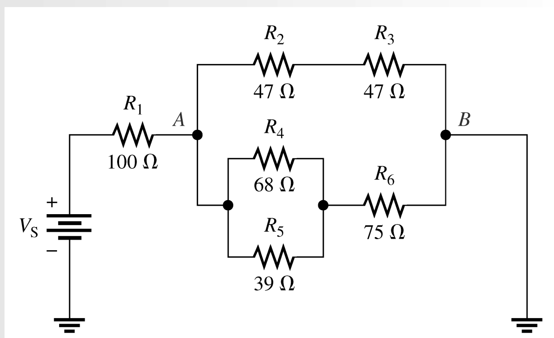
Related Problem Determine R_T in Figure 5–16 if R_3 is changed to 82 Ω.

Open Multisim file E06-06; files are found at www.prenhall.com/floyd. Using the multimeter, verify the calculated value of total resistance. Change R_1 to 18 Ω, R_2 to 82 Ω, and R_3 to 82 Ω and measure the total resistance.

EXAMPLE 5–7

Find R_T of the circuit in Figure 5–17.

▶ FIGURE 5–17



Solution **1.** In the upper branch between nodes A and B, R_2 is in series with R_3. The series combination is designated R_{2+3} and is equal to $R_2 + R_3$.

$$R_{2+3} = R_2 + R_3 = 47\ \Omega + 47\ \Omega = 94\ \Omega$$