Resistance is Utile: Or, An Homage to Ohmage

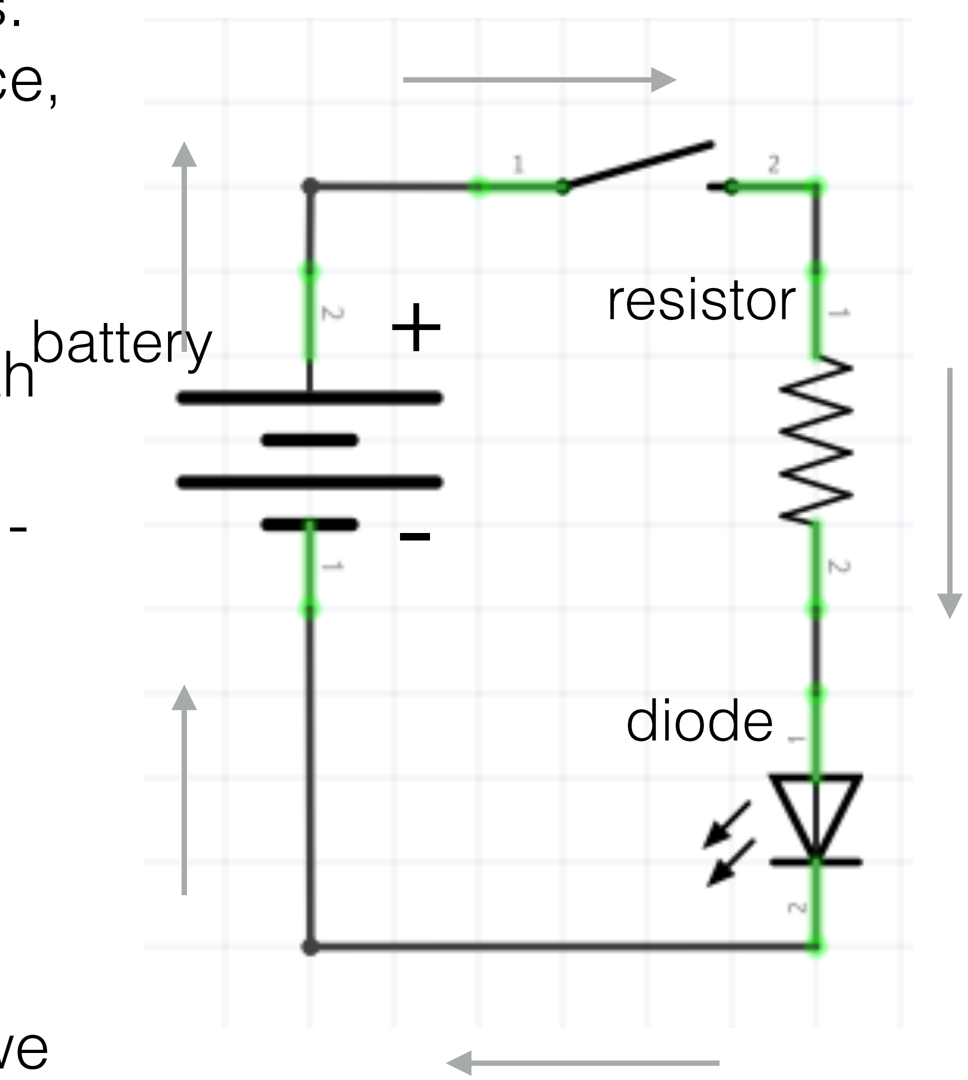
44-440/640-IoT

Objectives

- Students will be able to
  - explain what schematics are
  - identify symbols for resistors
  - distinguish between resistors connected in series and in parallel
  - calculate current, resistance, and voltage drop for a given circuit
  - understand how voltage dividers work

Schematics

- A schematic is a **representation of a circuit** using a set of more-or-less universally agreed upon symbols. When designing an IoT or any other electronic device, we start with a schematic
- At right we have a **battery** — represented as a a series of alternating short and long parallel lines, with the outside long line indicating the anode, and the outside short line the cathode. It may include + and - symbols.
- We also have a **resistor**, represented by a jagged line, and a diode, represented by a triangle and line (more on that in a moment)
- Current flows from higher voltage to lower voltage: we will always depict current as flowing from + to -



Resistors

- A resistor is a cylindrical object that *resists* the flow of electric current. Colored bands around the resistor indicate its resistance in ohms.

- Value = (1st Digit || 2nd Digit) * Multiplier

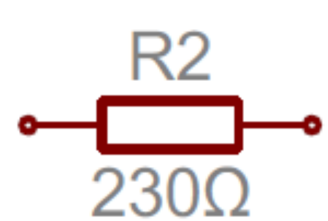
Concatenate

- 4th band indicates accuracy as a %.

- There are 4,5 and 6 band resistors. We will only use 4 band resistors.

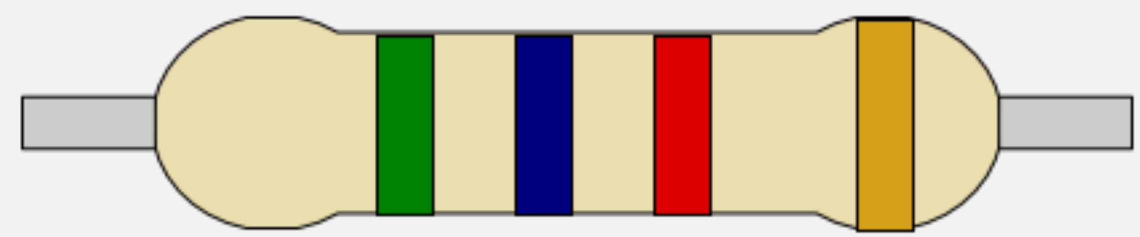
- In many parts of the world, the symbol for a resistor is a rectangle, but we will use a zig-zag symbol in this course.

US



International

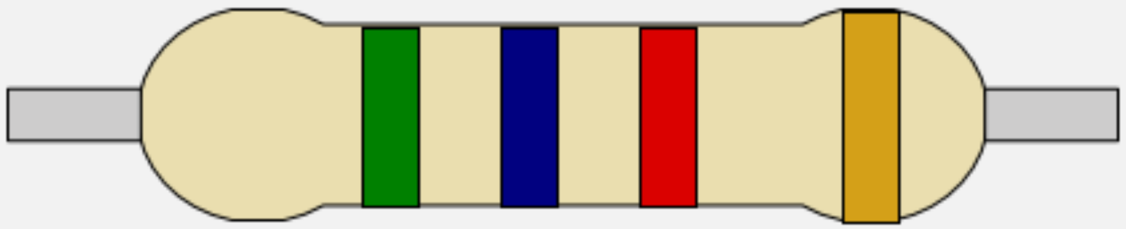
4 Band Resistor



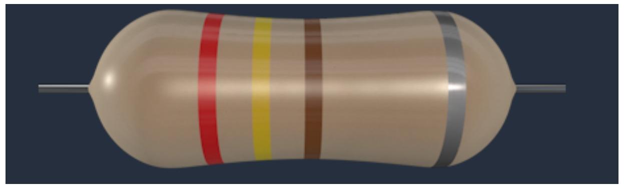
	1st Digit	2nd Digit	Multiplier	Tolerance
Black		0	x1	
Brown	1	1	x10	± 1%
Red	2	2	x100	± 2%
Orange	3	3	x1K	± 3%
Yellow	4	4	x10K	± 4%
Green	5	5	x100K	± 0.5%
Blue	6	6	x1M	± 0.25%
Violet	7	7	x10M	± 0.10%
Grey	8	8	x100M	± 0.05%
White	9	9	x1G	
Gold			÷ 10	± 5%
Silver			÷ 100	± 10%

Decoding Resistor Bands

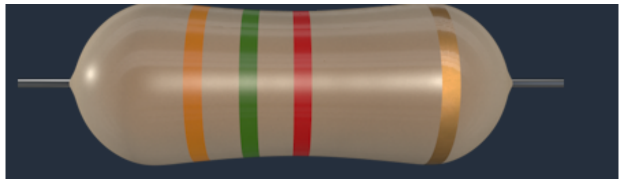
4 Band Resistor



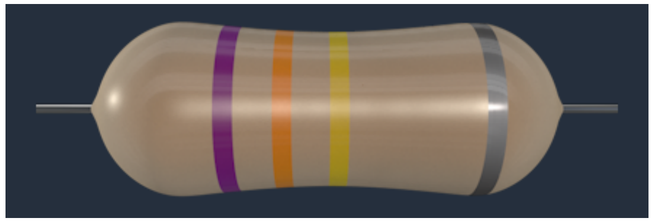
	1st Digit	2nd Digit	Multiplier	Tolerance
Black		0	x1	
Brown	1	1	x10	± 1%
Red	2	2	x100	± 2%
Orange	3	3	x1K	± 3%
Yellow	4	4	x10K	± 4%
Green	5	5	x100K	± 0.5%
Blue	6	6	x1M	± 0.25%
Violet	7	7	x10M	± 0.10%
Grey	8	8	x100M	± 0.05%
White	9	9	x1G	
Gold			÷ 10	± 5%
Silver			÷ 100	± 10%



240Ω ± 10%



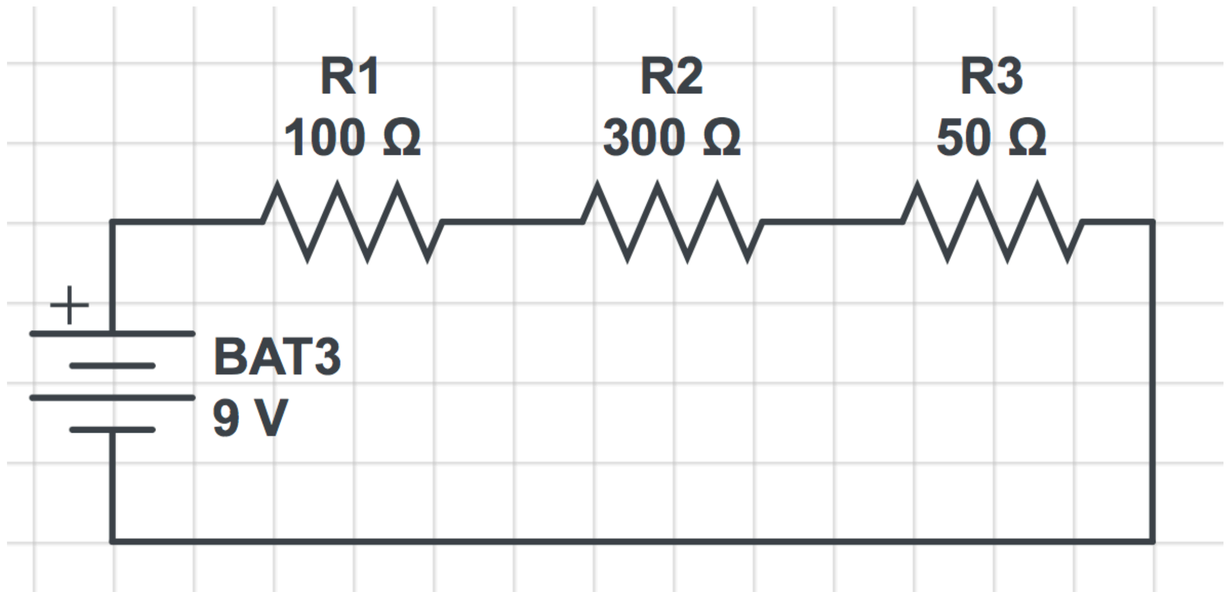
3500Ω ± 5%



????

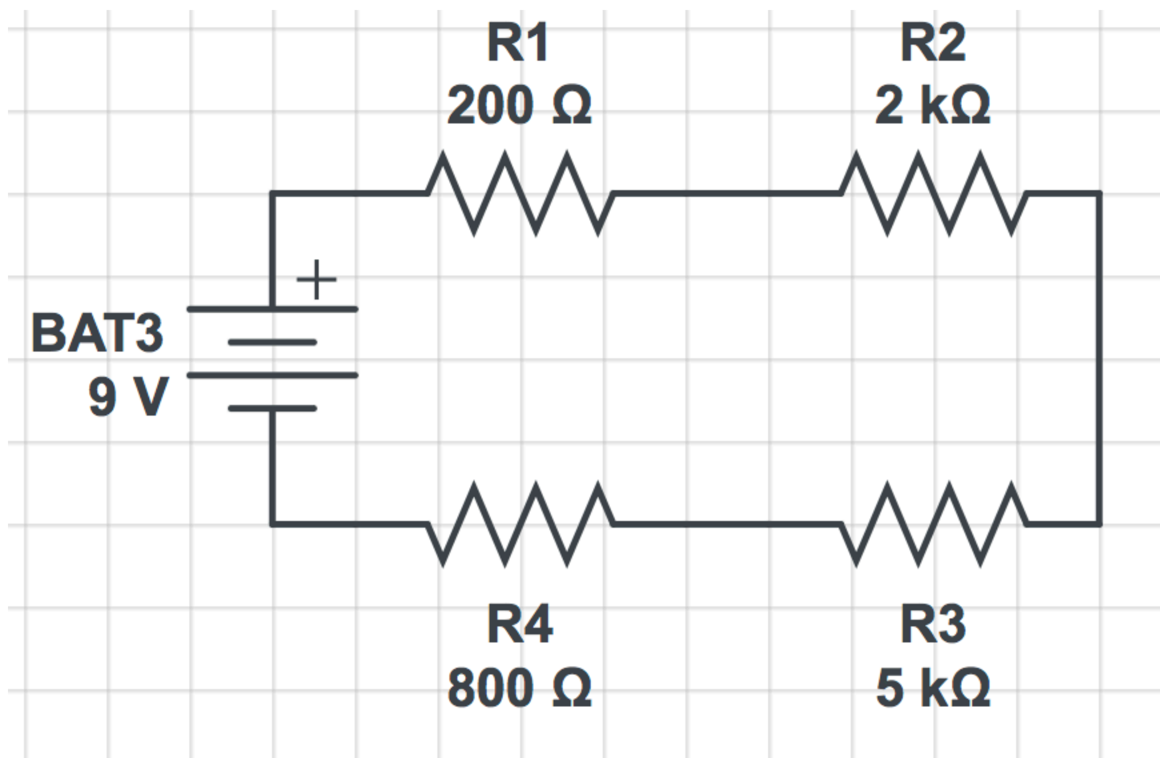
Resistors in Series - Current

- Resistors can be connected in series — in a straight line.
- In this case, the total resistance of the circuit is the **sum** of the resistance of the individual resistors
- Here, RT = R1 + R2 + R3 = 100 + 300 + 50 = 450 Ω
- These 3 resistors are therefore equivalent to a single 450Ω resistor
- The current is the same throughout the entire circuit, because there is only one path for the electrons to follow.
- I = V / R = 9 / 450 = 0.020 A = 20 mA

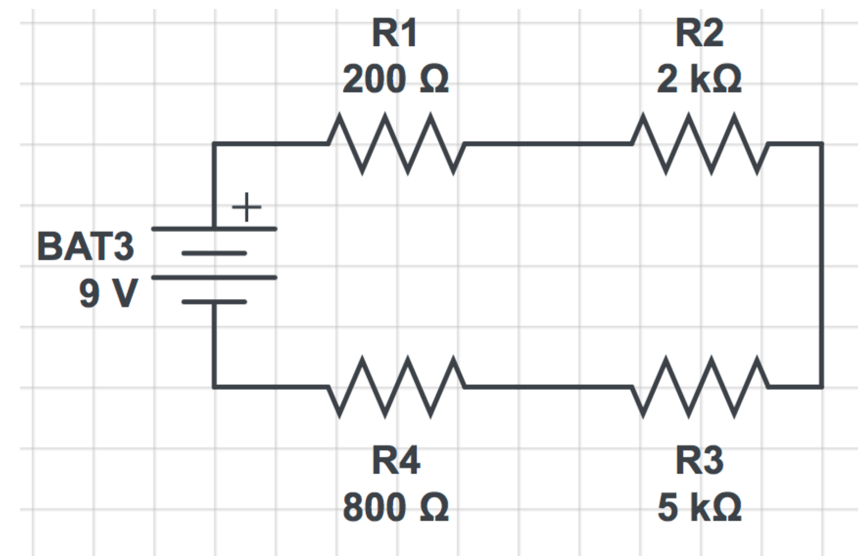


ICE: Resistors in Series - Current

- What is the total resistance?
- What is the voltage?
- What is the current?



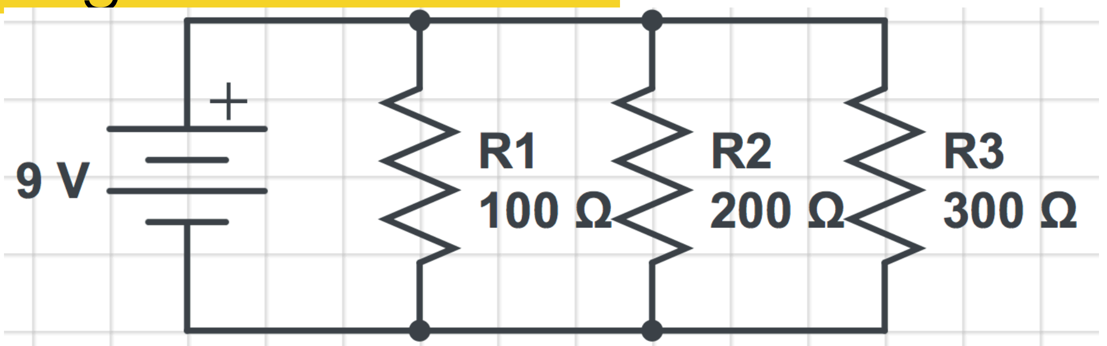
ICE: Resistors in Series Solution



- $R = 200 + 2000 + 800 + 5000$
  $= 8000\ \Omega$
- $V = 9$
- $I = V / R = 9 / 8000 = 0.001125\text{ A} = 1.125\text{ mA}$

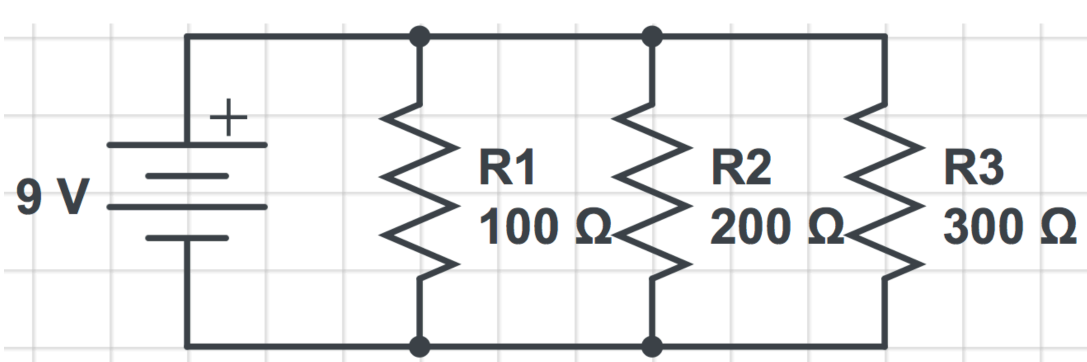
Resistors in Parallel

- Resistors can also be arranged in parallel
- This offers more paths for the electrons to get from one side of the battery to the other, so *more current will flow*, meaning that the equivalent resistance will *decrease*
- Given n resistors in parallel, $RT = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \ldots + \frac{1}{Rn}}$
- Here $RT = \frac{1}{\frac{1}{100} + \frac{1}{200} + \frac{1}{300}} = 54.5\Omega$
- These 3 resistors are therefore equivalent to a single 54.5Ω resistor
- The current, however, is *not* the same through all 3 resistors

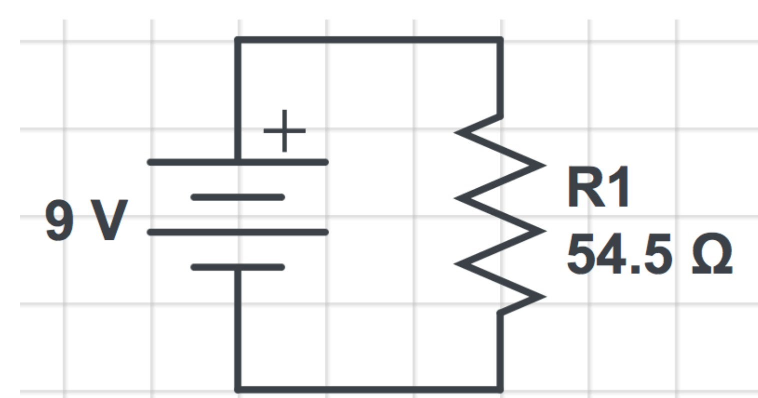


Resistors in Parallel

- With resistors in series, current was uniform throughout the circuit
- Here, there will be **more current through the smaller resistors**.
- RT = 54.5Ω; V = 9; I = 9 / 54.5 = 0.165 A = 165 mA = total current
- Since I = V/R applies to each resistor, we have:
- I1 = 9/100 = 90 mA; I2 = 9/200 = 45 mA; I3 = 9/300 = 30 mA
- 90 + 45 + 30 = 165 mA, so life is good

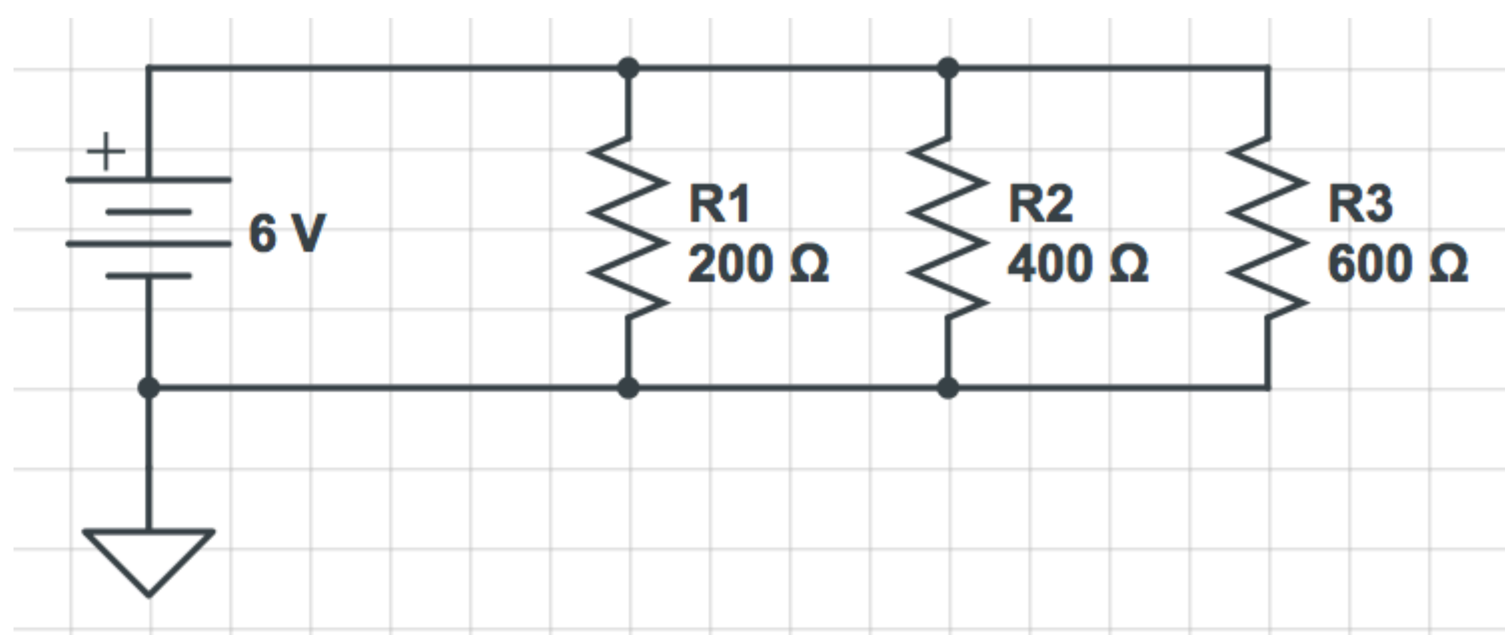


==



ICE: Resistors in Parallel

- Find
  - total resistance of the circuit, RT
  - total current through the circuit, I
  - current through each resistor, I1, I2, I3

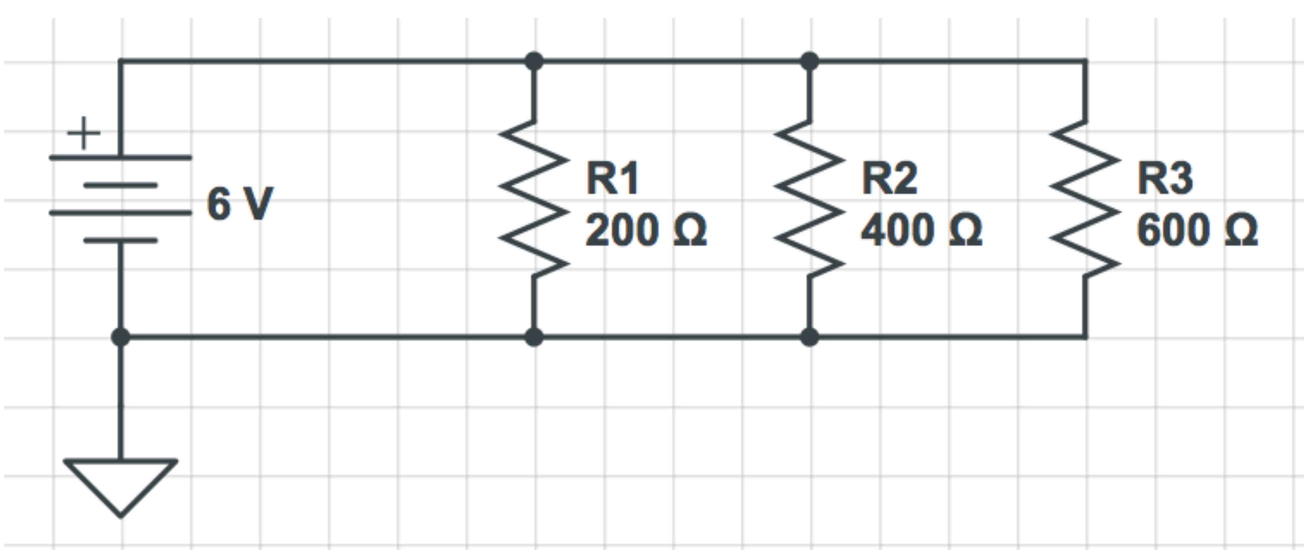


ICE: Resistors in Parallel Solution

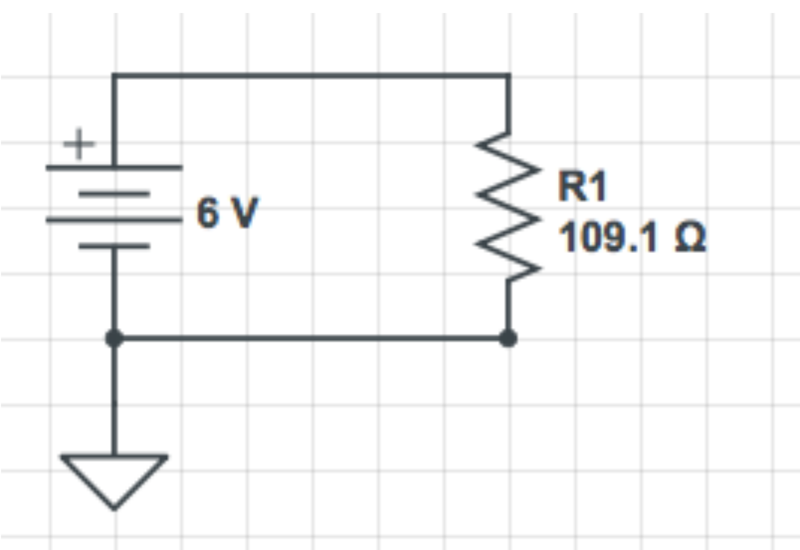
- total resistance of the circuit

$$RT = \frac{1}{\frac{1}{200}+\frac{1}{400}+\frac{1}{600}} = 109.1$$

- total current through the circuit:
  - I = V/R = 6 / 109.1 = 0.055 = 55 mA
- current through each resistor: I1 = V/R1 = 6/200 = 0.030 = 30 mA
- I2 = V/R2 =6/400 = 0.015 = 15mA
- I3 = V/R3 = 6/600 = 0.010 = 10 mA
- Check: 55 = 30 + 15 + 10 ✓

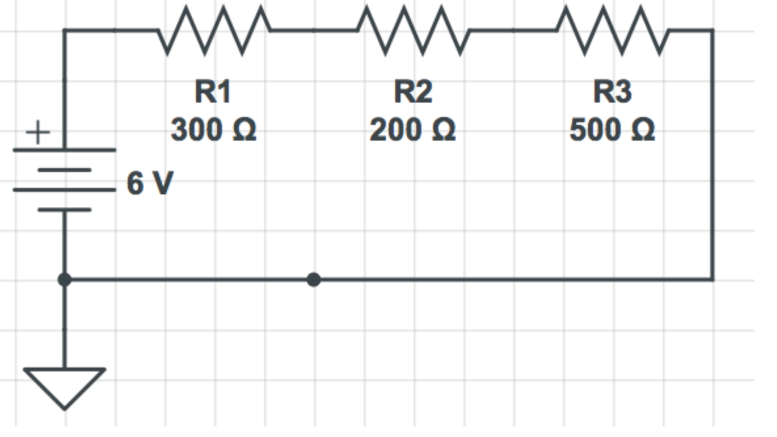


==



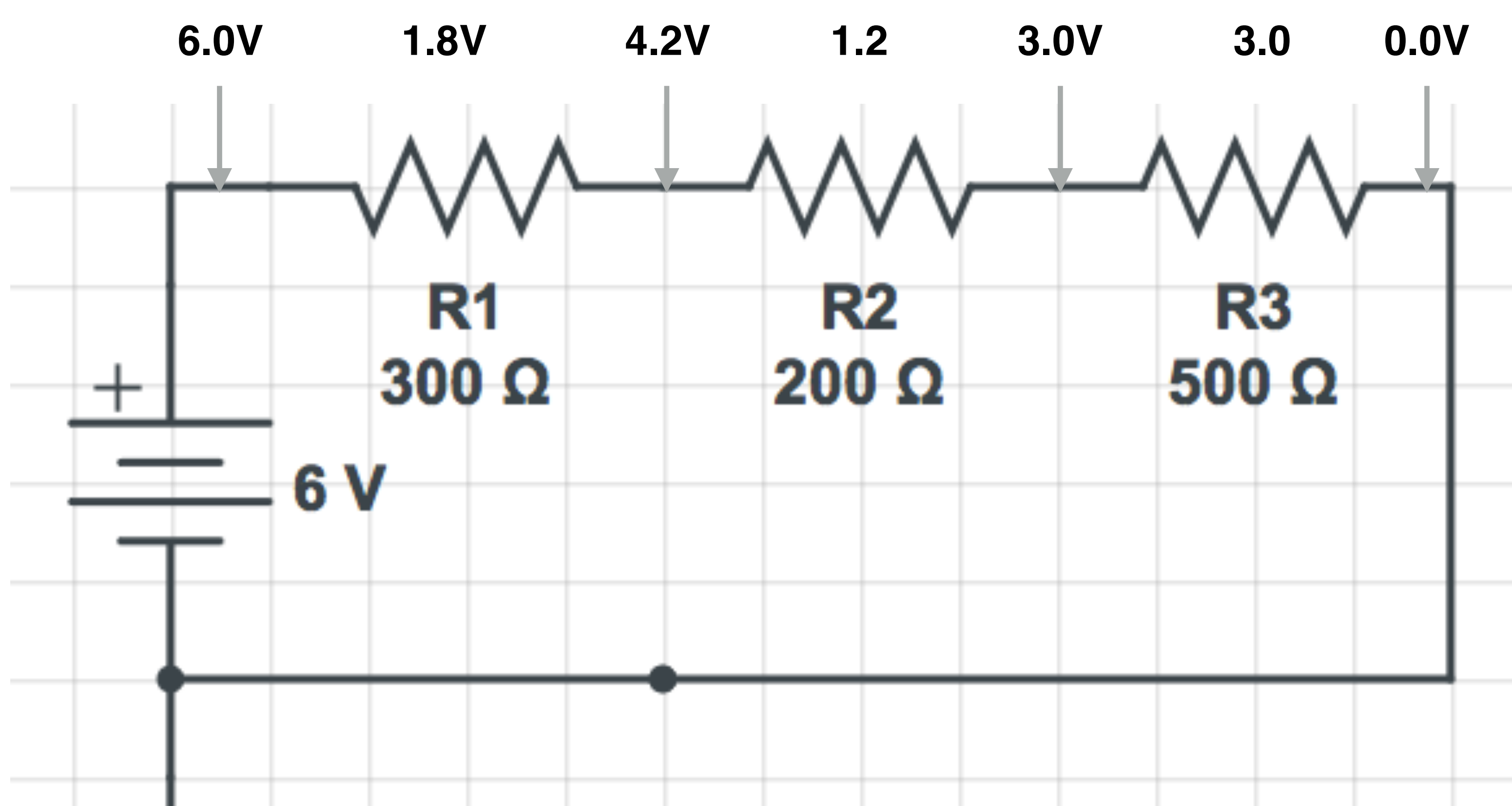
Resistors in Series - Voltage

- When resistors are arranged in series, the current is the same throughout the circuit, but the voltage is not
- The voltage drops across each resistor, because that resistor uses energy (it gets converted into heat).
- The amount of voltage drop is given by Ohm's law: V=IR
- For example, in the circuit at right I = V/R = 6/1000 = 0.006 = 6 mA
- Voltage drop across R1 is V = I * R1 = 0.006 * 300 = 1.8 V
- Voltage drop across R2 is V = I * R2 = 0.006 * 200 = 1.2 V
- Voltage drop across R3 is V = I * R3 = 0.006 * 500 = 3.0 V
- Total voltage drop = 1.8 + 1.2 + 3.0 = 6 V



Resistors in Series - Voltage

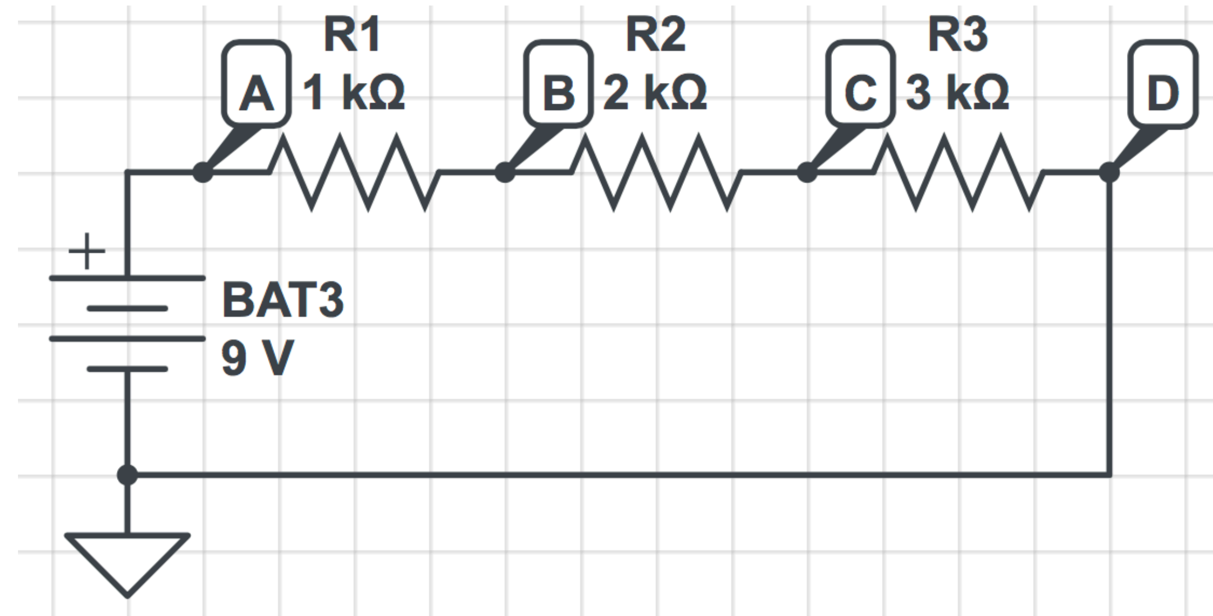
- Voltage drop across R1 is V1 = I * R1 = 0.006 * 300 = 1.8 V
- Voltage drop across R2 is V2 = I * R2 = 0.006 * 200 = 1.2 V
- Voltage drop across R3 is V3 = I * R3 = 0.006 * 500 = 3.0 V
- Total voltage drop = 1.8 + 1.2 + 3.0 = 6 V



Kirchoff's Voltage Law

- If we interpret the voltage drops as negative, we have the following:
- Total voltage drop = 1.8 + 1.2 + 3.0 = 6 V
- 6 - 1.8 - 1.2 - 3.0 = 0
- This is an example of **Kirchoff's Law**, that states that in a loop (resistors in series), the sum of the voltages (with the source voltage being positive, the drops being negative) always equals 0

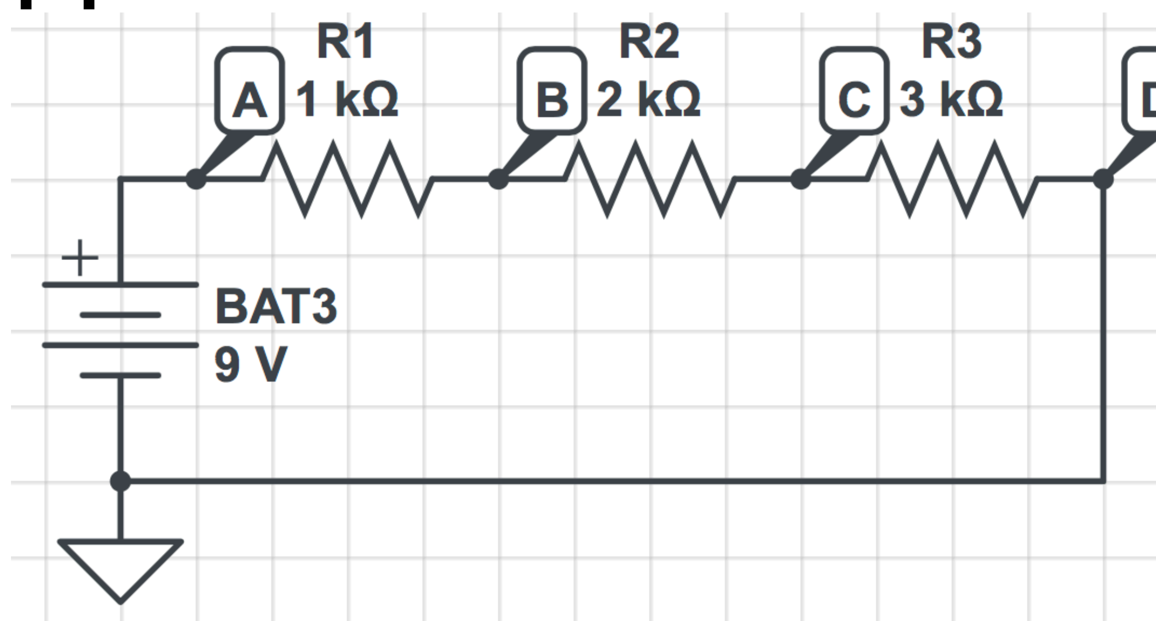
ICE: Resistors in Series



- Get an account on ciricuitlab.com
- Create a 3-resistor circuit as shown
- Run the simulation
- Put the cursor over points A-D and record V and I at those locations

Location	Voltage (V)	Current (mA)	Voltage Drop From Previous Node
A	VA:		-
B	VB:		VB-VA:
C	VC:		VC-VB
D	VD:		VD-VC

ICE: Resistors in Series Solution



- Get an account on ciricuitlab.com
- Create a 3-resistor circuit as shown
- Run the simulation
- Put the cursor over points A-D and record V and I at those locations

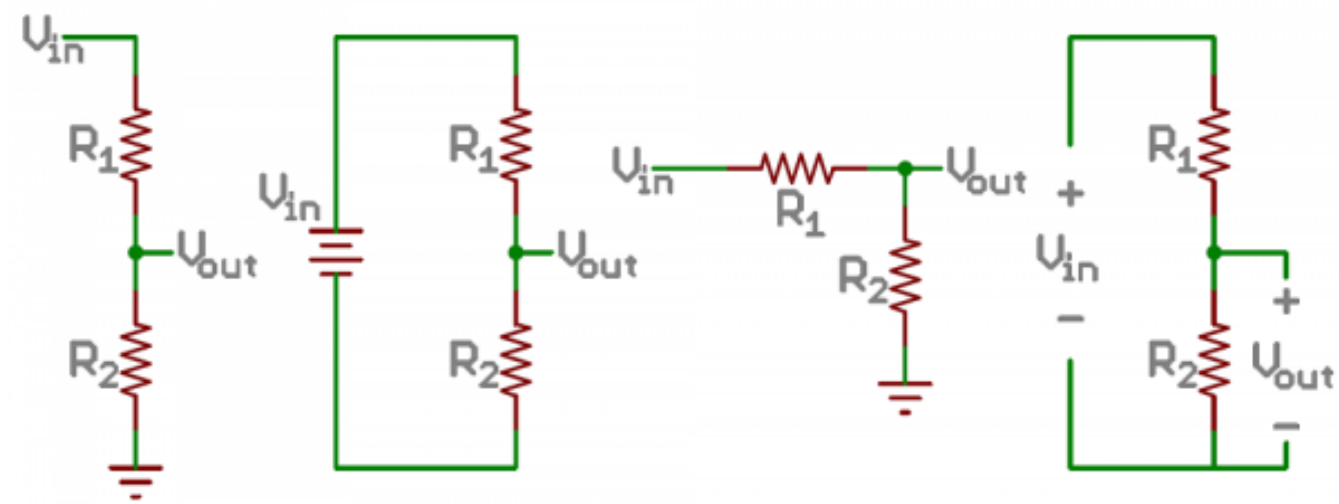
Location	Voltage (V)	Current (mA)	Voltage Drop From Previous Node
A	VA: 9	1.5	-
B	VB: 7.5	1.5	VB-VA: 1.5
C	VC: 4.5	1.5	VC-VB: 3.0
D	VD: 0	1.5	VD-VC: 4.5

A Voltage Divider

- A voltage divider is a circuit with **two** resistors in series, and a **tap** between them. The depictions may vary, as shown at right, but they are functionally equivalent.

- Vout is based on the fraction of the total resistance due to R2, which makes sense*.

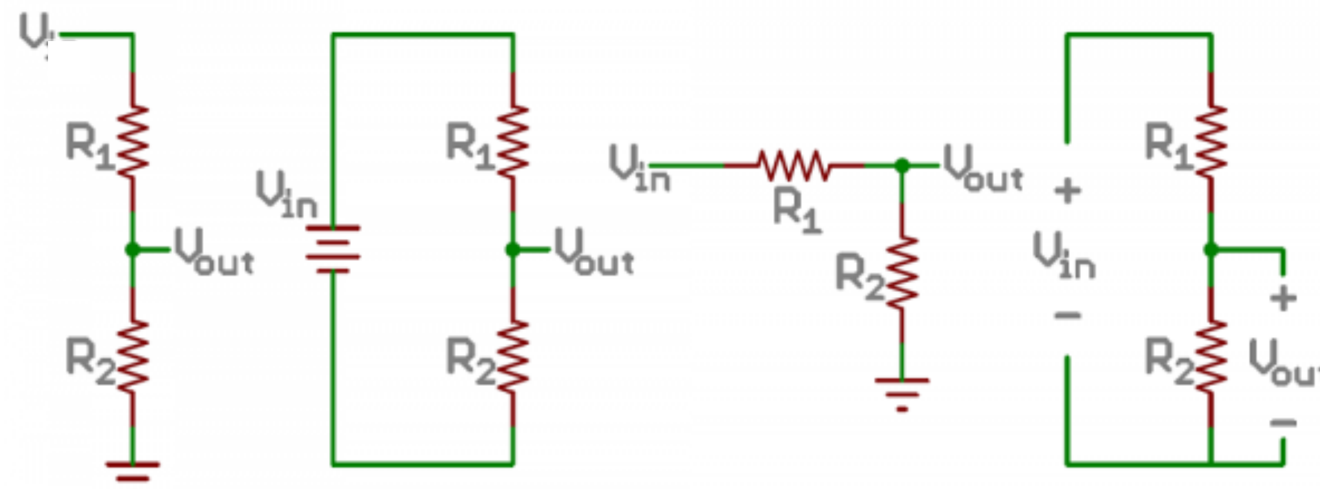
- While a voltage divider might seem esoteric, it is a critical circuit that finds application repeatedly throughout this course



$$Vout = Vin \cdot \frac{R2}{R1 + R2}$$

*think of the H2O metaphor, where voltage == pressure. If most of the resistance is in R2, then most of the voltage drop is going to occur there (so Vout will be closer to Vin); if most of the resistance is in R1, then most of the voltage drop will occur there, so Vout will be closer to 0. Sure enough, a large R1 will drive R2/(R1+R2) to zero, and thence Vout to 0.

Voltage Divider: The Derivation



- I = V/(R1 + R2)
- V1 = I*R1 = V/(R1 + R2)*R1
- Vout = V - V1 = V - V/(R1 + R2)*R1 = V*R2/(R1+R2)

Potentiometers and Photoresistors

- A potentiometer is a variable resistor -- changed by turning a a knob
- A photoresistor is a resistor whose resistance depends upon the light striking it.
- We will defer discussion of these until we need them

Exercises

1. Draw a symbol for a battery, resistor, and switch
2. Find the resistance of a resistor that is
    1. Red, Green, Orange
    2. Violet, Black, Green
    3. Are all red, red, brown resistors 220 Ω? Discuss.
3. What does it mean for resistors to be in series? In parallel?
4. A circuit with a 6V power source has 3 resistors in series -- 300, 600 and 100 Ω. Find:
    1. the total resistance of the circuit
    2. the current through the circuit - is it the same everywhere?
    3. the voltage drop across each resistor

Exercises

5. A circuit with a 9V power source has 3 resistors in parallel -- 200, 400 and 600 Ω. Find:

    1. the total resistance of the circuit

    2. the current through the entire circuit

    3. the current through each resistor

6. A voltage divider has 2 resistors, 1000 and 500 Ω. Find Vout, assuming that Vin is 10V.

7. What is a potentiometer?

8. What is a photoresistor?

Programming Exercises

1. Design a C++ program to calculate RT for resistors arranged either in series or in parallel. It should prompt the user for the circuit type and the number of resistors, and return the resistance. *How* you design this circuit is as important as the result, so think about how you would modularize this.

2. Add another function to the previous program to provide voltage divider functionality. The user will specify Vin, Vout, and R1. Your function should return R2. Include some sort of meaning option to choose between calculating RT and R2.

3. Optional: Redo your program, adding a GUI.

Resources

- Bayle, Julien. *C Programming for Arduino*. Packt Publishing, 2013.
- https://learn.sparkfun.com/tutorials/what-is-electricity
- http://www.colorado.edu/physics/phys1120/phys1120_fa09/LectureNotes/Voltage.pdf
- Monk, Simon. *Hacking Electronics:An Illustrated DIY Guide for Makers and Hobbyists*. McGraw-Hill, 2013.
- https://www.ampbooks.com/mobile/tutorials/lesson-002/
- https://www.eeweb.com/toolbox/4-band-resistor-calculator/
- http://www.mi.mun.ca/users/cchaulk/eltk1100/ivse/ivse.htm#
- http://www.nutsvolts.com/magazine/article/which-way-does-current-really-flow
- https://learn.sparkfun.com/tutorials/capacitors
- http://www.electronics-tutorials.ws -- nice set of tutorials
- http://www.electronics-tutorials.ws/resistor/res_3.html
- http://www.instructables.com/id/How-To-Diodes/