PS1: ISIM

Tuesday, February 9, 2021 4:28 PM

PS1_
Resistors

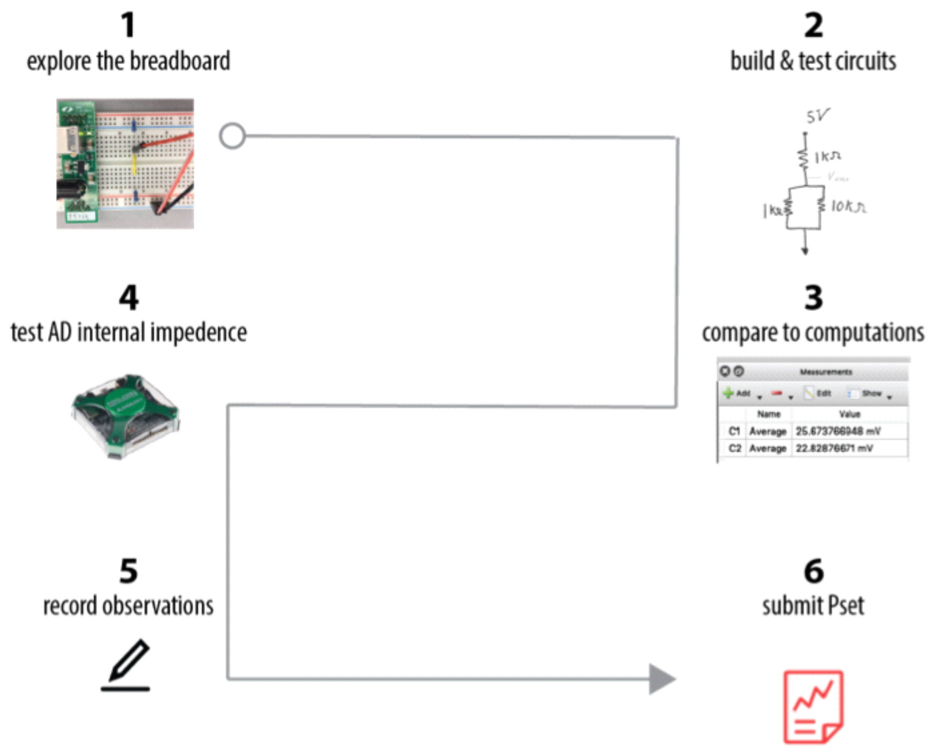
PSet 1: Resistors in series and parallel

Goal: Use a breadboard and resistors to measure how the resistance changes when resistors are connected in series and in parallel.

Learning objectives

- Describe the hidden wiring pattern beneath a breadboard;
- Use your power supply and breadboard to construct resistor circuits;
- Contrast theoretical voltages with measured values;
- Calculate the output of a voltage divider;
- Measure the effect of the instrument's internal impedance

Visual Summary



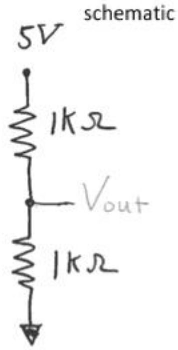
1. Explore the breadboard

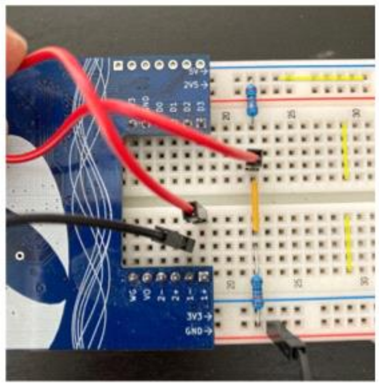
To get started this week, let's use our breadboard and conduct a few very simple experiments with resistors.

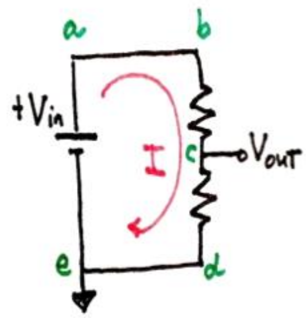
Reference: The tutorial video on the solderless breadboard explains how the basic connections work.

Below we show two equal resistors in series across 5 volts. *Some* of the hidden connections beneath the breadboard are indicated with the superimposed yellow lines.

schematic

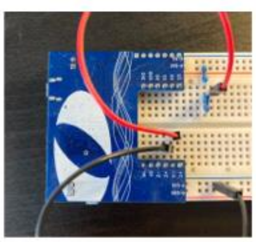






The two different schematics are equivalent ways of sketching the circuit (although the resistors in the photo are not 1kΩ). The schematic on the right reminds you that all the components are connected on a complete, closed path *circuit* where the current, *I*, flows. The one on the left is an easy reminder of our breadboard layout with the +5V breadboard "rail" and the 0V (↓ or Ground) breadboard "rail".

In this case we are using your breadboard's power supply to provide the constant +5 V.



Ch1 will measure the ΔV=Ch1+-Ch1-. Which are true?

Ch1 = $+V_{in} - V_{out}$ *Ch1=V_{out}* *Ch1=V_c-V_d*

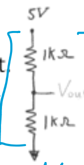
The circuit at the left is intended to be the same as above. R1=R2=1 k, but the voltage reading is nothing but noise.

Can you find the 5 errors? *(Answers on p. 4)*

Ch1- connects to 3V3, not GND
2nd res doesn't go anywhere
1st res connects to 2V5
Ch1+ connected to nothing
Missed: Power not connected

2. Build & test the resistor circuits

Using your breadboard, and power supply and best practices, build the following circuit.



$5V = I\,2k\Omega$
$I = \frac{5}{2}A$
$V_{out} = I\,1k\Omega$
$V_{out} = \frac{5}{2}1k\Omega$

Attach the measuring instrument to the circuit with jumper wires so that:

- Ch1+ measures V_{out} relative to Ground (this requires Ch1+ and Ch1- connections);

> Scope computes a running average for the time window.
>
> If the time window is too small or too large, the Average value will be distorted.
>
> 1 ms/div should be a sufficient time base.

Assuming the power supply output is+ 5 V=V_{in} and each of the resistors are 1.0 kΩ, what idealized voltage do you expect for V_{out}? $V_{out} = IR$ $V_{out} = \frac{5}{2}V$

Your V_{out} reading is likely to be different from the expected value.

Which, if any, of the assumptions about V_{in} or R values do not match reality?
↳ $V_{in} = 5.2V$

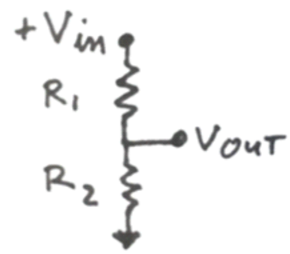
How do the deviations from the ideal values affect V_{out}?
↳ $V_{out} = V_{in}/2$, measured $V_{out} = 5.2V$

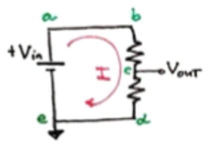
Now that you have the basic idea, analyze and construct each circuit in Table 1 and record the measured and expected voltage in the Table. Fill out the table on the following page.

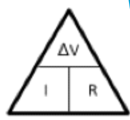
Each of the circuits in the table is a *voltage divider*. In each, the $+5V_{in}$ "drops" over the top and bottom resistors, thereby *dividing* the voltage, V_{in}.

What is the correct equation for V_{out} for a voltage divider?

(Can you derive it? It may help to remember that the notation to the right is a shortcut for a circuit)







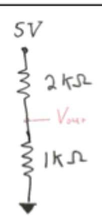
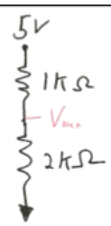
$V_{in} = I R_{total}$

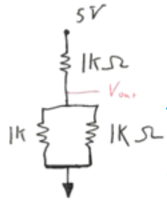
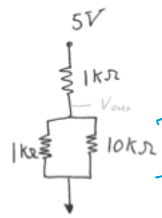
$I = \frac{V_{in}}{R_{total}}$

$V_{out} = R_2 I$

$V_{out} = R_2 \frac{V_{in}}{R_{total}}$

Answers from p. 2: 1. The power supply is not plugged in; 2.R2 has both ends in the same row, which has the effect of wiring the resistor ends of R2 together, creating an electrical short; 3. The Ch1+ is not connected to the circuit; 4. The R1 and R2 are not electrically connect to the ground to complete the circuit; 5. Ch1- is connected to 2.5V rather than ground.

Circuit	Expected V_{out} (include a short calculation)	Measured V_{out}
	$V_{out} = 1\cancel{k}\,\frac{5V}{3\cancel{K}}$ $= \frac{5}{3}V$ $= 1.67V$	1.73V
	$V_{out} = 2k\,\frac{5V}{3K}$ $V_{out} = 3.3V$	3.46V

 $\frac{1}{2} = \frac{1}{\frac{1}{1}+\frac{1}{1}}$	$V_{out} = 0.5k \frac{5V}{1.5K}$ $= 1.65V$	1.73V
	$V_{out} = 1000K \frac{5V}{1001K}$ $= 4.995V$	5.10V
 $\frac{1}{1+0.1}$ $= 0.91$	$V_{out} = 0.91K \frac{5V}{1.91K}$ $= 2.38V$	2.47V

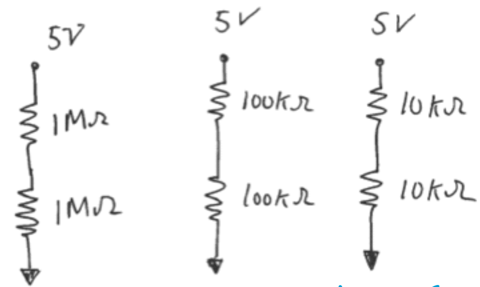
3. Compare measured V_{out} to theoretical V_{out}

What patterns, if any, emerge from the results? measured is always higher, which checks w/ $V_{in} = 5.2V$

Talk to a colleague to compare your results and emergent patterns.

4. Test the effect of the instrument's internal impedance

Build and test the following three voltage dividers. All are the same basic circuit and in theory should give the same measured voltage - only the overall value of the resistor is changing.



$5.22V = I \; ?\Omega$ $\qquad$ $V = 5.22V \; @ \; X\Omega$

Circuit	Measured voltage between resistors
1M resistor	2.28
100K resistor	2.56
10 K resistor	2.6

Notice that while you might expect that all circuits would have the same voltage between the two resistors, this is not what you measure. The reason for the departure is that the measurement device has an internal resistance ("input impedance"-- see section 2.4 of the course book for an explanation), so that it acts as if you've added a resistor in parallel to the resistor that it is measuring. This internal resistor has a resistance that we call "internal resistance" or "internal impedance."

From the three measurements, infer the approximate value of the input impedance/resistance. Include your calculation and measurements.

What value of input impedance for the instrument best explains your data?

Value of instrument input impedance (resistance):____________________________

$$2.28 = I\left(10^{-6} + \frac{1}{x}\right)^{-1} \Rightarrow \frac{10^{-6} + x^{-1}}{I} = \frac{1}{2.28}$$

$$10^{-6} + x^{-1} = \frac{I}{2.28}$$

$$\frac{1}{x} = \frac{I}{2.28} - 10^{-6}$$

$$\frac{1}{x} = \frac{I}{2.28} - 10^{-6}$$

$$x = \frac{1}{(I/2.28) - 10^{-6}}$$

$$2.56 = I\,(10^{-5} + \tfrac{1}{x})^{-1} \Rightarrow \frac{10^{-5} + x^{-1}}{I} = \frac{1}{2.56}$$

$$10^{-5} + x^{-1} = \frac{I}{2.56}$$

$$x^{-1} = \frac{I}{2.56} - 10^{-5}$$

$$x = \left(\frac{I}{2.56} - 10^{-5}\right)^{-1}$$

$$\left(\frac{I}{2.28} - 10^{-6}\right)^{-1} = \left(\frac{I}{2.56} - 10^{-5}\right)^{-1}$$

$$\frac{I}{2.28} - \frac{I}{2.56} = 10^{-6} - 10^{-5}$$

$$I\left(\frac{1}{2.28} - \frac{1}{2.56}\right)$$

$$I = \frac{10^{-6} - 10^{-5}}{\left(\frac{1}{2.28} - \frac{1}{2.56}\right)} = -1.876e-5$$

$$2.6 = I\,(10^{-4} + \tfrac{1}{x})^{-1}$$

Class 2. Resistors in series and parallel

5. Record your observations

Resistor intuition isn't bad once you're used to it. Resistor math is frustrating

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Take a minute to record for yourself what you noticed.

This is for your own learning.

6. Submit PSet

For these types of assignments you do not need to write a lab report. You can write your numbers in the tables and spaces provided. Please include supporting hand calculations.

These assignments are only checked for completeness – not fully corrected.

While anything you turn in should be neat and any analysis should be clear, you do not need to type anything up. You can just scan your hand-written work.

Also, many weeks you might not complete all questions as there is something you don't understand. That is perfect. Just complete as much as you can, turn that in, and then come to next class with questions. These assignments are meant to be a bridge from the course content on circuits to the lab experiments.

You can always go back and complete and re-submit any of these assignments.