In this laboratory, we will explore the use of digital multi-meters (DMMs) in the measurement of resistance and voltage sources.

Resistors

Typical low power resistors are in the form of cylindrical objects with axial leads[1] or connectors. The resistor value is usually indicated by a series of 3 color bands with most times ` 4th band representing the resistor's tolerance. t

	digits		multiplier
	band 1	**band 2**	**band 3**
black		0	1
brown	1	1	10
red	2	2	100
orange	3	3	1 000
yellow	4	4	10 000
green	5	5	100 000
blue	6	6	1 000 000
violet	7	7	
grey	8	8	
white	9	9	
gold			0.1
silver			0.01

tolerance	
band 4	
1%	brown
2%	red
5%	gold
10%	silver

http://www.matrixtsl.com/courses/ecc/uploads/resistorcolor4band.png

Sometimes, as many as 6 bands may be used.

The most basic carbon composite resistors have 3 bands: the first two bands represent the resistor value and the 3rd band is the power of 10 multiplier for that value. The assumption is that the tolerance is 20%.

Four stripe resistors use the 4th stripe to indicate tolerance. For tighter tolerances, i.e. greater accuracy, a 5 band color code is used, but no specific convention is rigorously followed by manufacturers. High accuracy resistors are frequently marked numerically rather than using color bands.

The physical size of the composite resistor indicates its power dissipation ability. Common composite carbon resistors have power ratings ranging from 1/16th to 2 Watts.

1 https://www.ebay.com/itm/Axial-Leads-1W-470-Ohm-Metal-Oxide-Film-Resistor-1-Watt-100-Pcs-/322450292440

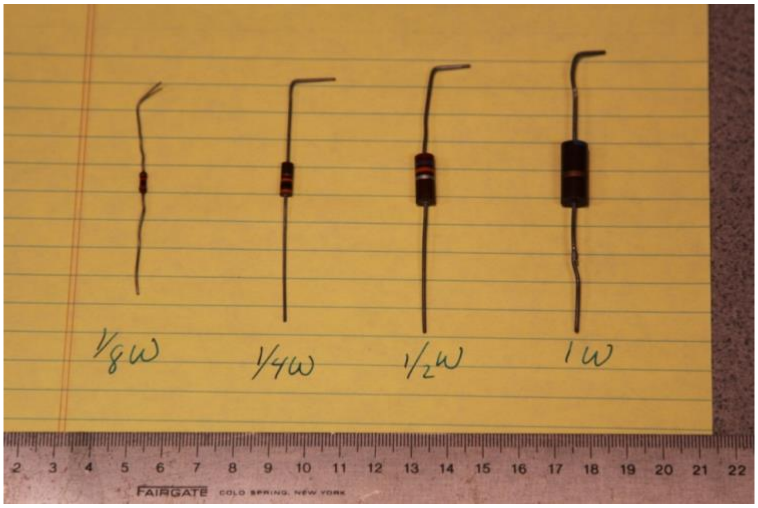
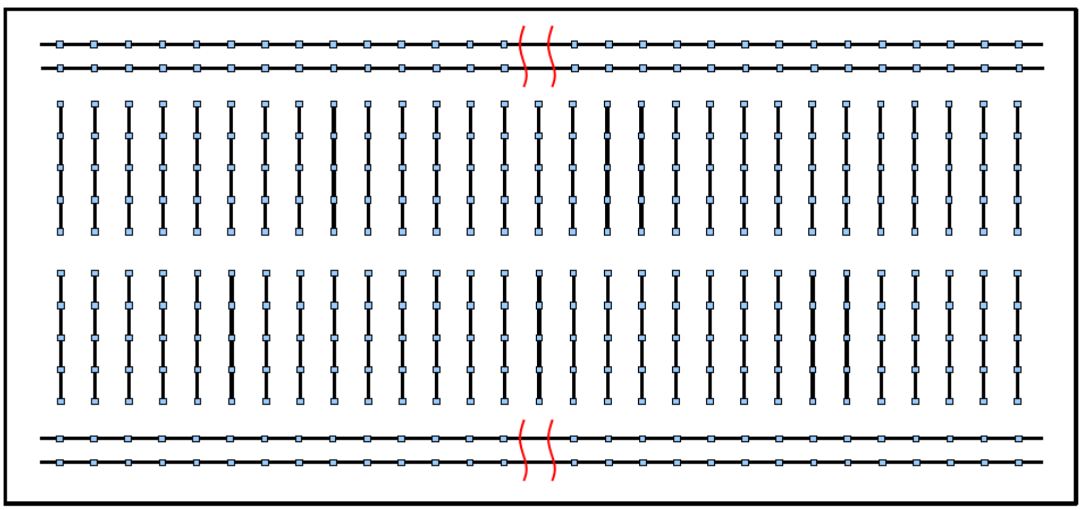


FIGURE 1-1. VARIOUS POWER RATED RESISTORS

Breadboard Interconnection Diagram:



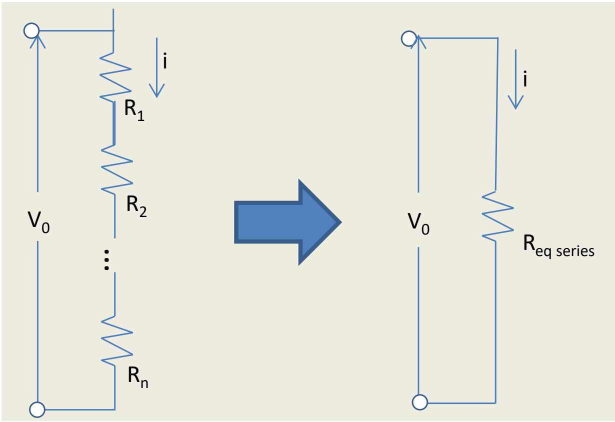
For our labs, your electrical components will be placed into breadboards. A breadboard will have exposed holes for your components to be inserted. As shown above, holes are electrically connected internally into rows and columns.

Series and Parallel Combinations of Resistors

WARNING: in some breadboards the horizontal strips may be disconnected at the position of the red markings, i.e., the horizontal strips on the upper left will not be electrically connected to the strips on the upper right. The same goes for the horizontal strips on the bottom.

If resistors are placed in parallel or series, their behavior with respect to current and voltage can be exactly replaced by a single resistor. Consider the following situations:

Series



From the left diagram:

$$V_0 = iR_1 + iR_2 + \cdots iR_n$$

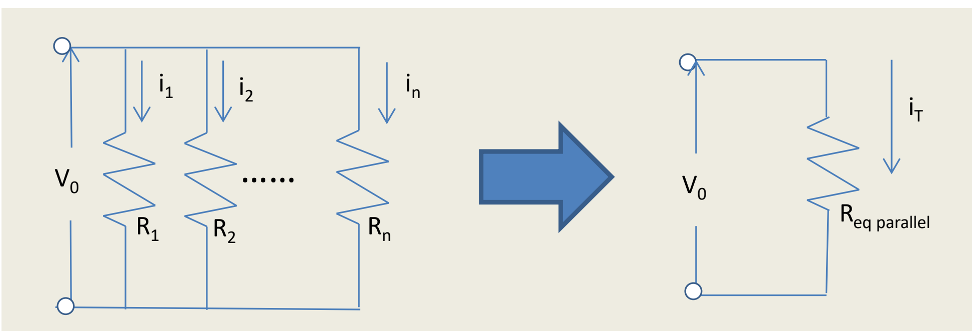
So $V_0 = i\sum_{i=1}^{n} R_i$, or $\frac{V_o}{i} = \sum_{i=1}^{n} R_i$

From the right diagram:

$$V_0 = iR_{eq\ series}, \text{ or } \frac{V_0}{i} = R_{eq\ series}$$

Therefore, $R_{\text{EQ,Series}} = \sum_{i=1}^{n} R_i$

Parallel



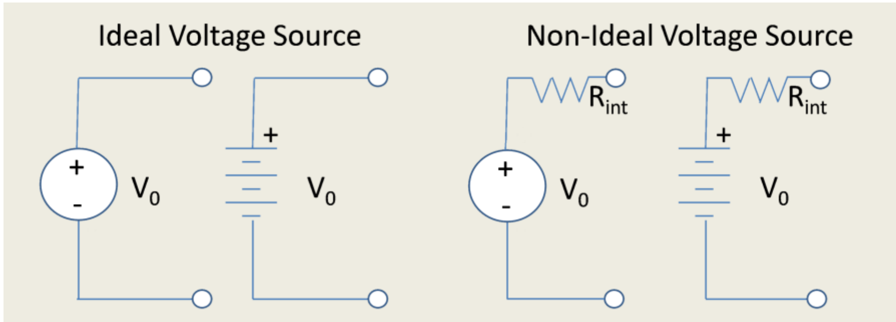
From the left diagram: $i_T = i_1 + i_2 + \cdots + i_n = \frac{V_0}{R_1} + \frac{V_0}{R_2} + \cdots + \frac{V_0}{R_n} = V_0 \sum_{i=1}^{n} \frac{1}{R_i}$

From the right diagram: $i_T = \frac{V_0}{R_{eq\ parallel}}$ Therefore, $R_{\text{EQ parallel}} = \frac{1}{\sum \frac{1}{R_i}}$

Voltage Sources

Voltage sources are either ideal or non-ideal. An ideal voltage source is usually represented as shown below: a circle with + and – signs and a voltage value or a series of long and short lines [this representation comes from original diagrams of a battery]

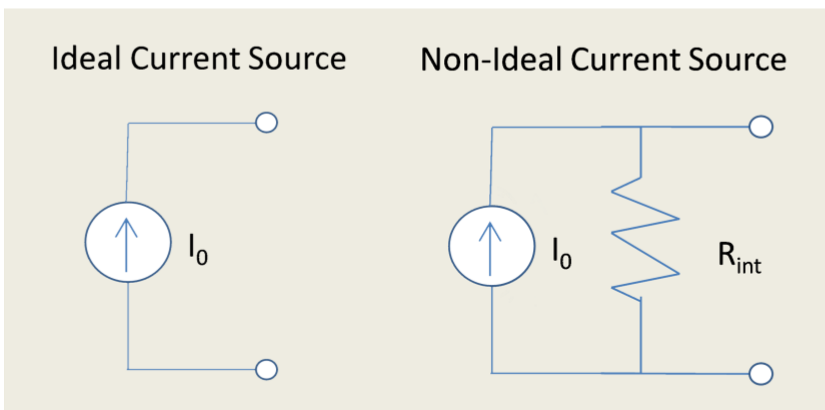
An ideal voltage source would produce a constant potential difference regardless of the current it needs to supply. Real or non-ideal power supplies are represented as an ideal source and a series resistance R_{int} the equivalent internal resistor. The non-ideal voltage source approaches ‘ideal’ as $R_{int} \rightarrow 0$.



[The Non-Ideal Voltage Source is also called a Thevenin Source]

Current Sources

Current sources also occur in ideal and non-ideal types. An ideal current source delivers a constant current no matter what voltage is required. They are usually shown by a circle with an arrow showing the direction of the current.

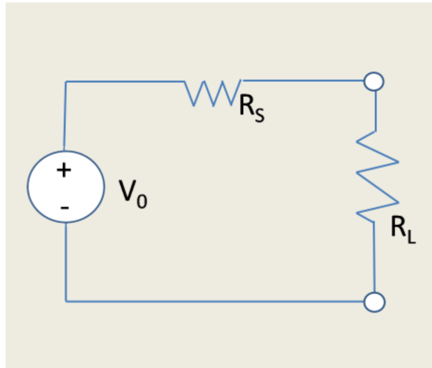


[The Non-Ideal Current Source is also called a Norton Source]

Non-ideal sources are usually represented by an ideal source with an internal parallel resistor.

The non-ideal source approaches ‘ideal’ as $R_{int} \rightarrow \infty$.

One can use a constant voltage source to simulate a nearly ideal constant current source by placing a very large resistance in series, i.e.



The current through the load resistor R_L can be found as:

$$V_0 = i\,(R_L + R_S).$$

Therefore,

$$i = V_0 / (R_S + R_L)$$

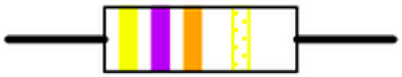
If $R_S >> R_L$, then $i \approx V_0/R_S$ (a constant value providing $R_S >> R_L$).

We will not have you perform current source experiments at this time because **current measurements are the easiest way to destroy a meter**.

Week 1 Prelab

Briefly answer the following questions. Name:

1. Identify the resistors: UID:



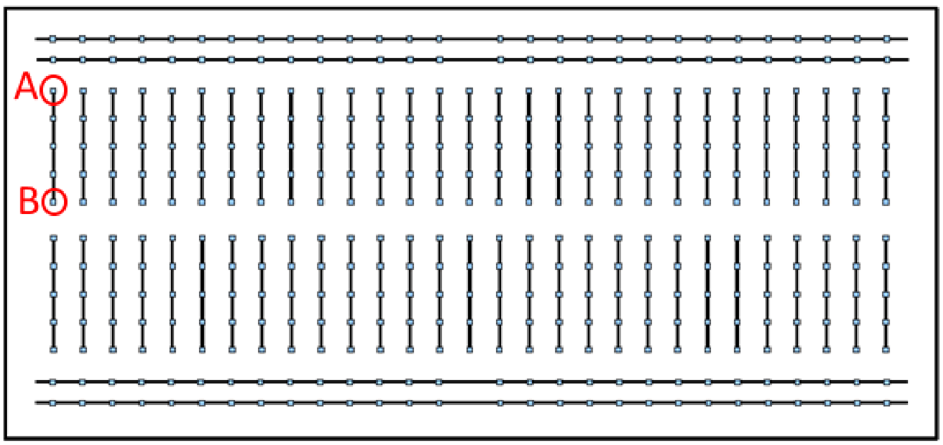
Yellow-Violet-Orange-Gold

____Ω with a tolerance of +/- ____%.

Brown-Black-Yellow-Silver

____Ω with a tolerance of +/-____%.

2.



If a resistor is inserted into the breadboard with one leg at point A and one leg at point B, what resistance will an ohmmeter measure for that resistor? Why? What should you do instead to measure the proper resistance?

3. Draw the I-V curves for the following diagrams

(a) Ideal voltage source

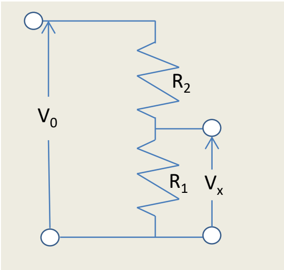
(b) Non-ideal voltage source

(c) Ideal current source

(d) Non-ideal current source

4. Prove the voltage and current divider equations: They are basic and very commonly used equations that you should memorize for use in all your future electronics courses.

Voltage Divider

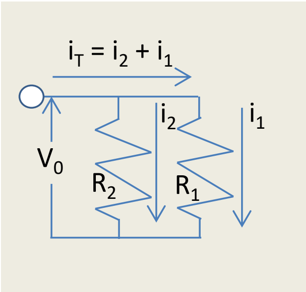


Problem: show that

$V_x = V_0 R_1/(R_1+R_2)$

YOUR SOLUTION HERE:

Current Divider



Problem: show that

$I_1 = i_T R_2/(R_1+R_2)$

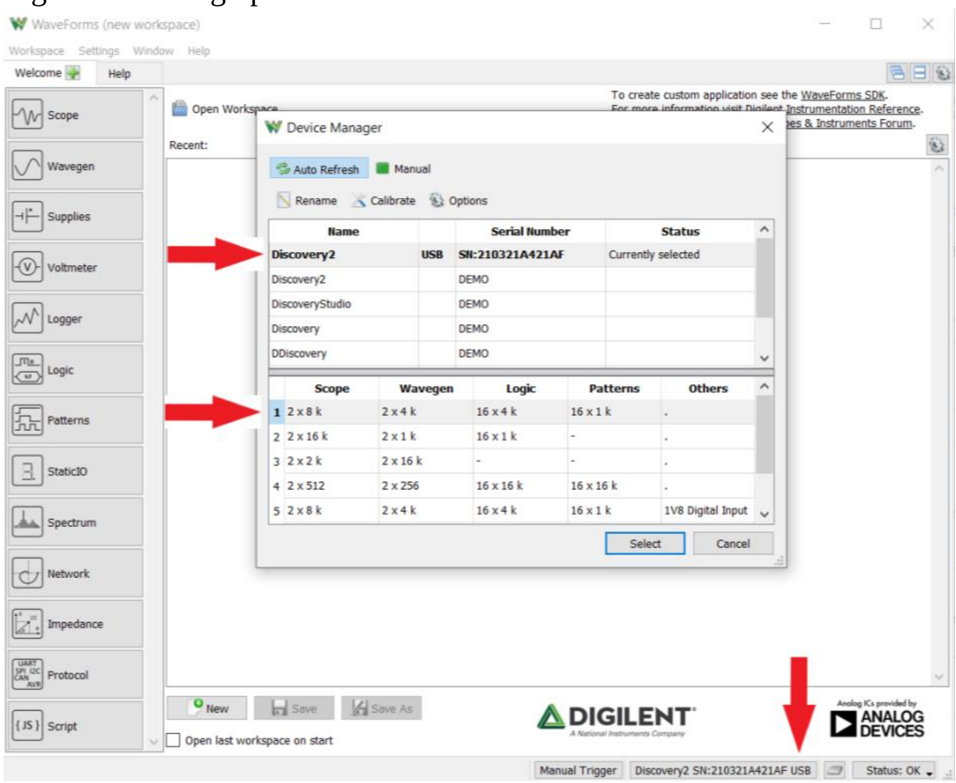
YOUR SOLUTION HERE:

Week 1 Prelab End

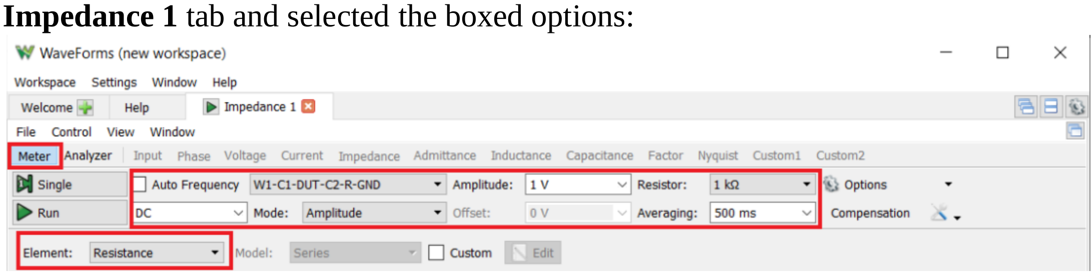
Using the AD2 Impedance Analyzer

In place of a DMM's ohmmeter, we will be using the AD2's Impedance Analyzer to measure resistor values.

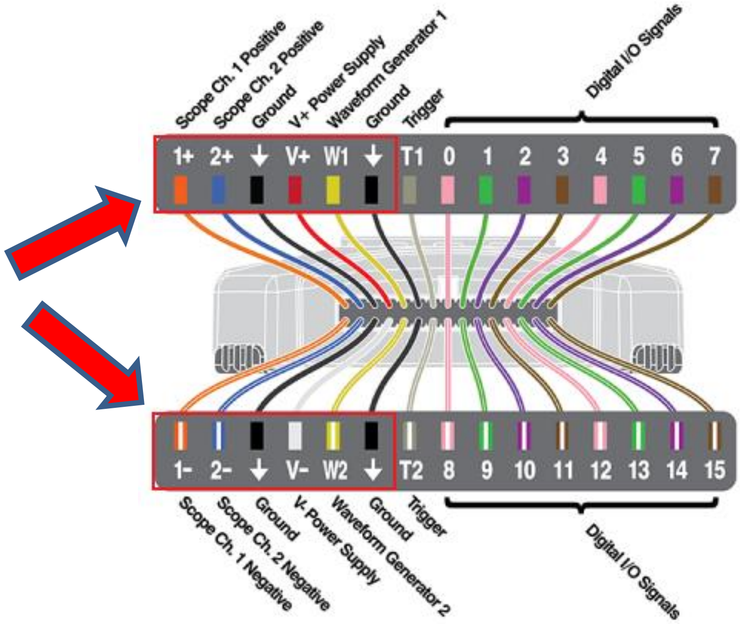
1. Launch the WaveForms software with the AD2 connected via USB. Ensure that you have the default settings selected in the Device Manager. This can be done by selecting the button in the bottom-right labeled "Discover2 SN:************ USB" and selecting the following options:



2. Select the Impedance Analyzer in the Welcome menu. Choose the **Meter** view in the **Impedance 1** tab and selected the boxed options:

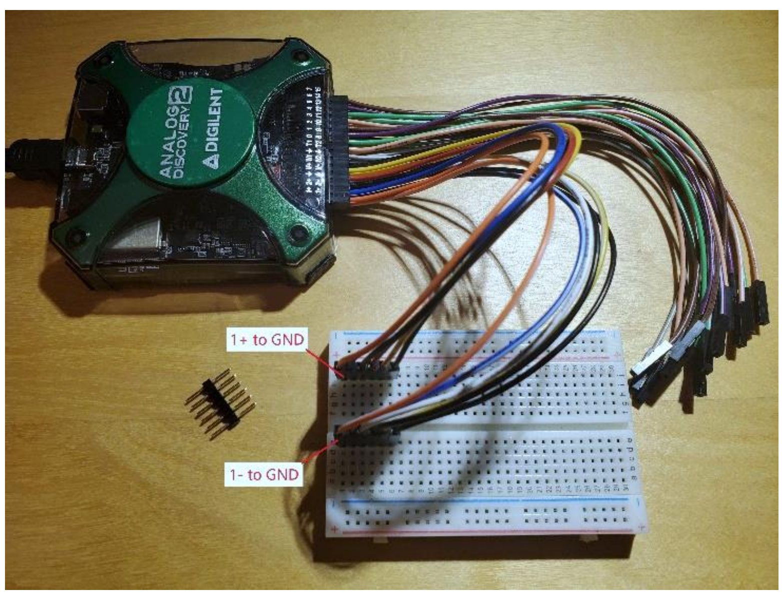


3. Now that you have the software setup, we look at the hardware. Here is a diagram (also included with your unit) of how the AD2's flywire cables are arranged:



https://reference.digilentinc.com/reference/instrumentation/analog-discovery-2/specifications

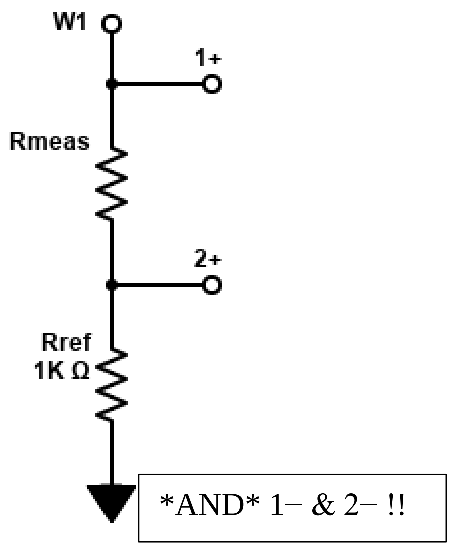
We only use the boxed left-most 2x6 cables.



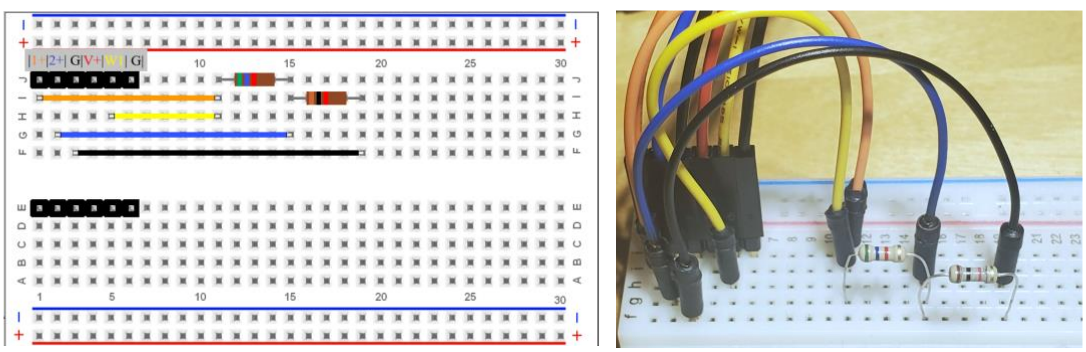
One (organized) way you might set up the AD2.
Use the rest of the board to place and connect components.

In this lab, we only use the boxed left-most 2x6 cables. It is suggested you connect these cables to your board in an organized manner. This will pay off when debugging your circuit.

4. Assemble the circuit below on your breadboard (you will find the breadboard diagram in the pre-lab helpful). Note that R_{meas} is the resistor you would like to measure and R_{ref} = 1K Ω is a reference resistor required for the Impedance Analyzer to function correctly. Ensure you have the AD2 pins connected correctly!



Circuit diagram



Example analyzer setup where R_{meas} = 5.6K Ω

5. When ready, click **Run** in the Impedance Analyzer and the resistance R_{meas} will appear.

The Impedance Analyzer works by the voltage divider principle (look at the pre-lab for a clue to what this principle is).

The AD2's Impedance Analyzer has a source of error we do not account for here (one that is not present when using a DMM). What is this error and what information do we need to minimize it?

ANSWER HERE:

Note: For the remainder of this lab, disregard this error (i.e. treat the Impedance Analyzer's measurements as truth).

Resistor Standard Values vs Tolerance

1. Pick 3 resistors with different color codes. If your resistors have 5 bands, consider only the first four bands. Measure their values with your AD2. Compare their stated values and tolerances (color code) with your measured analyzer results. (Do not exceed R_{ref} by a factor of 10)

WORK SHEET HERE:

$\frac{\text{MEASURED-MARKED}}{\text{MARKED}}(100\%)$

Resistor #	Marked	AD2 Measured	% Deviation from Marked
R_1	_________	_________	_________
R_2	_________	_________	_________
R_3	_________	_________	_________

Is the % Deviation greater or less than the indicated tolerance?

ANSWER HERE:

2. If you look at a standard list of 20% resistors available, you will see 1000 ohms and 1500 ohms but not 1200 ohms. Why? If you look at 5% resistors, would the results be different? Why? [An explanation of resistor values can be found at this site. Be sure to watch the video. Also, here.] Hint: Think about what tolerance means and how it differs from measurement error.

ANSWER HERE:

3. Pick two resistors that are approximately two orders of magnitude different e.g. 22 Ω and 2,200 (See Figures 1-2, 1-3, and 1-4. Do not exceed R_{ref} by a factor of 10)
   a. Measure them carefully. Note their actual values rather than the color code indicated value.
   b. Measure them in series and parallel connections.

WORK SHEET HERE:	
R_1 Measured Value: _______________	R_2 Measured Value: ________________
R_{Series} Value: _______________	$R_{Parallel}$ Value: _______________

   c. Compare R_{series} to the two individual resistors. Then compare $R_{parallel}$ to the two individual resistors.
   d. In the series connection, which resistor dominates the resistance measurement and why? Try to explain without using the equation.
   e. In the parallel connection, which resistor dominates the resistance measurement and why? Try to explain without using the equation.

ANSWERS HERE:

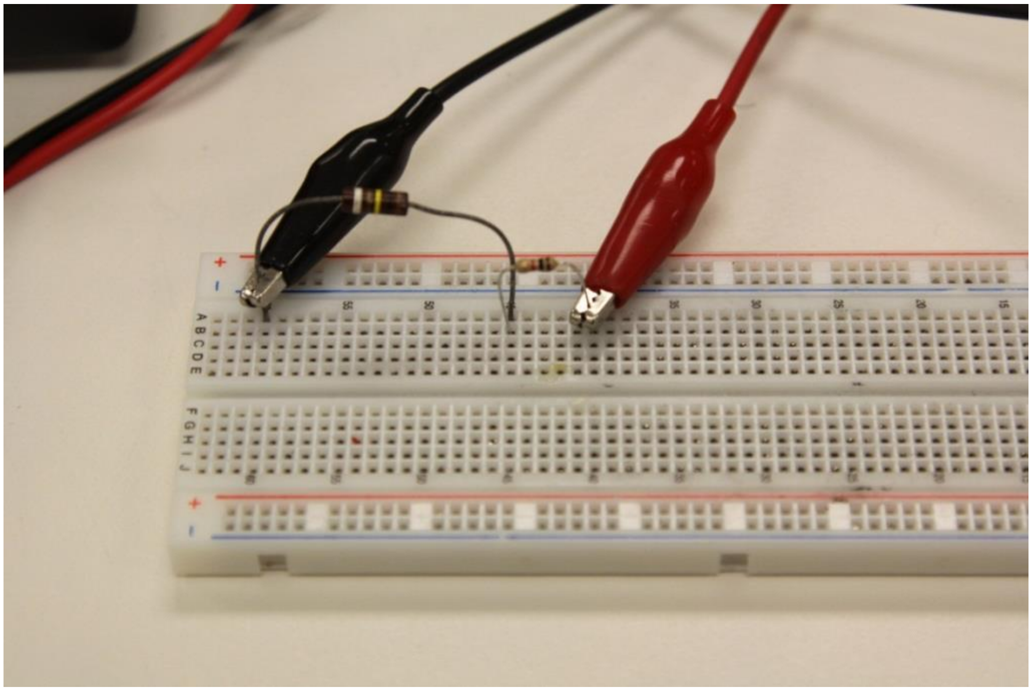


FIGURE 1-2. RESISTORS CONNECTED IN SERIES ON PROTO-BOARD

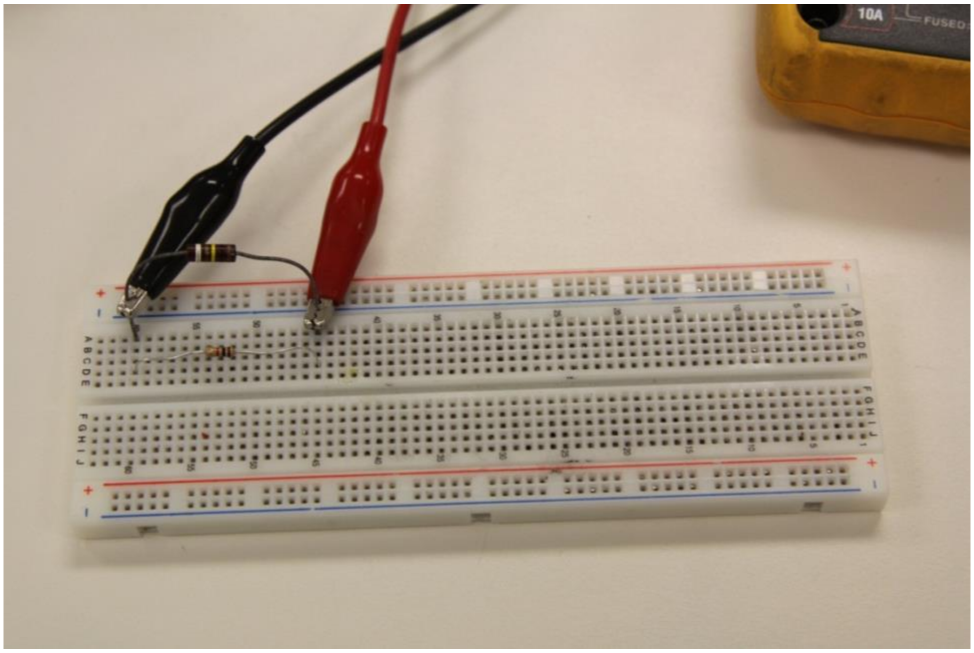
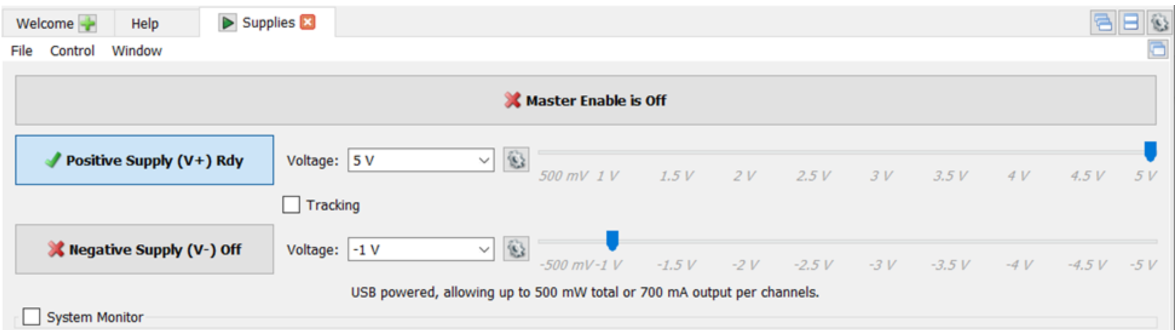


FIGURE 1-3. RESISTORS CONNECTED IN PARALLEL ON PROTOBOARD

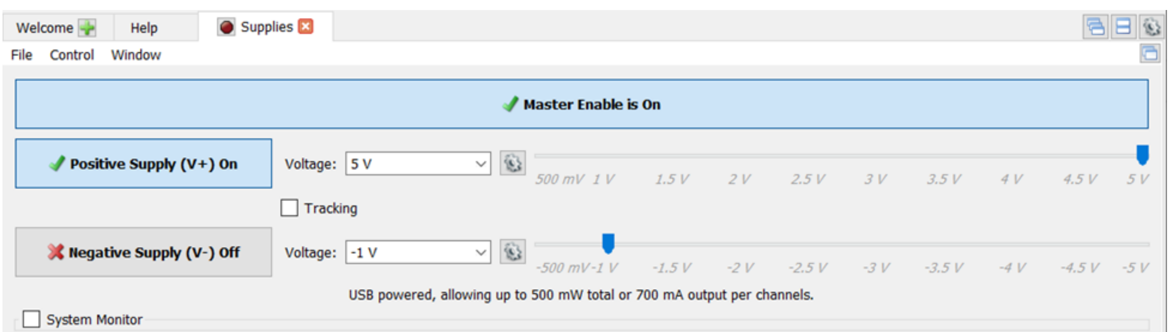
Passive Sign Convention

In this section, we will be using the AD2's Power Supply and Voltmeter

1. Open the WaveForms software with the AD2 connected to your computer. Ensure you have the Device Manager properly setup (as done previously).
2. Using the Power Supply:
   a. From the Welcome tab, select the **Supplies** option in the menu.
   b. In the Supplies tab, you will select the voltage you want to create at the V+ and V- terminals of the AD2.
   c. Once ready, put the supply(ies) you would like to use into the ready state by selecting the adjacent button and click the top **Master Enable** button to turn them on.

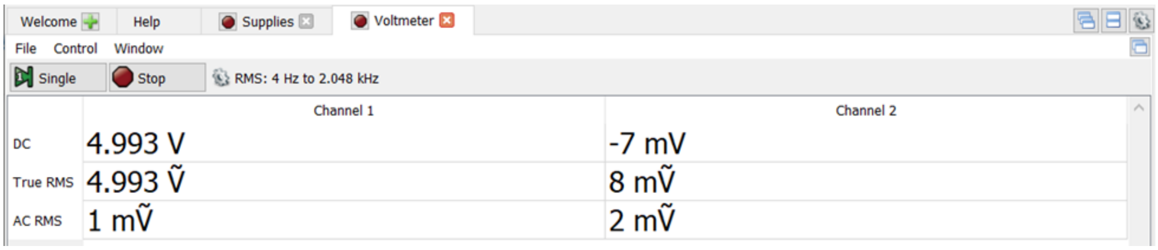


The V+ supply is set to +5 V and is in the ready state.



The V+ supply is enabled.

3. Using the Voltmeter:
    a. From the Welcome tab, select the **Voltmeter** option in the menu
    b. To make a measurement on Channel 1, connect 1+ and 1- at either end of the device whose voltage you would like to measure and click **Run**.



Measuring the V+ supply (set to 5 V) using Channel 1

We will now investigate Passive Sign Convention:

Materials:

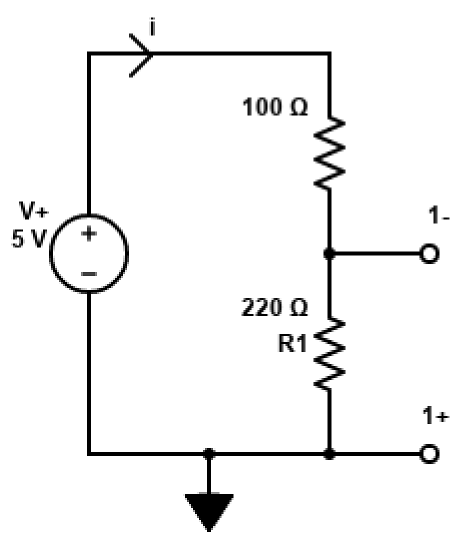
100 Ω Resistor

220 Ω Resistor

Breadboard

AD2

1. Build the following circuit on your breadboard:



2. After ensuring 1+ and 1- are connected as shown, answer the following:

WORK SHEET HERE:

Record your measurement v_{R1} at Channel 1: ___________

Solve for the current i (use labeled resistances): ___________

Calculate R1's power as: v_{R1} * i = ___________

3. Passive Sign Convention is a standard rule in circuit theory that denotes what the sign of a component's power is when it either absorbs or generates energy. Under this convention, a positive sign for power means a component is absorbing energy while a negative sign for power means a component is generating energy.

   If the previous steps were followed correctly, you will find that the calculated power for R1 does not make sense using Passive Sign Convention. Why does it not make sense (hint: notice how R1 is warm) and how can you correct this calculation?

ANSWER HERE:

Unloaded and Loaded Voltage Dividers

We will investigate the effect that loading has on a voltage divider circuit. Loading, as you recall from lecture, is the demand for current from a voltage source. That demanded current has an effect on the performance of the circuit. We will be measuring the amount of that performance change.

You will need the following components:

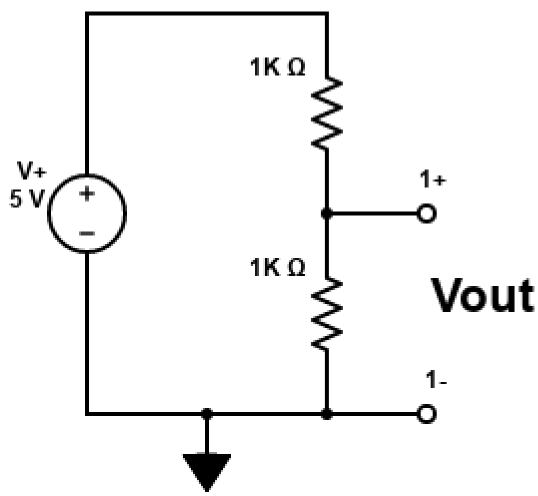
1 KΩ resistors (2)

3.3 KΩ resistor

Breadboard

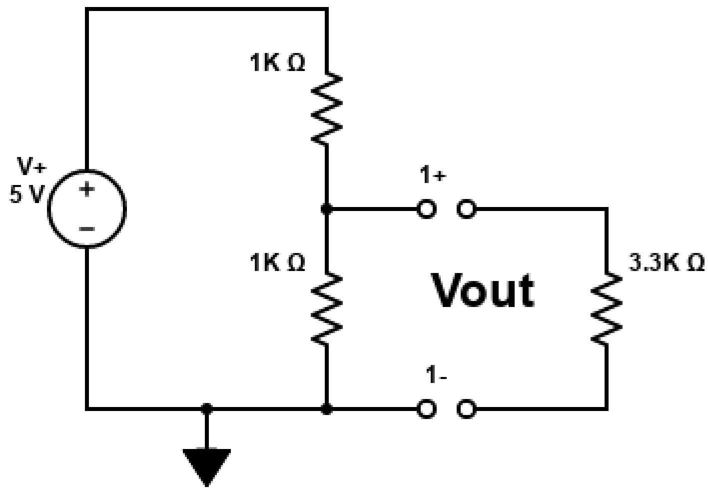
AD2

1. Construct the voltage divider circuit as shown below. This is an unloaded voltage divider.



2. Measure V_{out} at Channel 1 as shown. Record the value here ___________ .

3. Now load the circuit by attaching the 3.3 KΩ load resistor across the lower 1 KΩ resistor, as shown below. The 3.3 KΩ resistor is now demanding current from the voltage divider.



4. Measure the new V_{out} as in Step 2. Record the value here: __________ V
5. Fill out the following table:

	UNLOADED VOLTAGE DIVIDER	LOADED VOLTAGE DIVIDER
V_{out} (measurement)		
$V_{upper1K}$ (calculation)		
I_{total} (calculation)		

Why does an increase in total current result in lower output voltage of the loaded voltage divider circuit?