Experiment A3
Electronics I
Procedure

Deliverables: Checked lab notebook, printed plots with captions, derivation with pen and paper

Overview

Most of the transducers used in modern engineering applications are electronic, meaning they convert the physical parameter of interest to a voltage or current. The purpose of this lab is to familiarize you with the electronic equipment and techniques that you will need to connect and operate various sensors.

Part I: Voltage Divider

In this portion of the lab, you will construct the circuit shown in Figure 1 using R_1 = 1 kΩ. You will then measure V_{out} as a function of the resistance R_2. Copy the circuit diagram and table into your lab notebook.

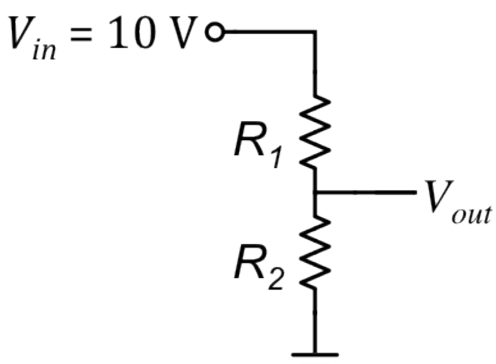


Figure 1 - Voltage divider circuit.

Table 1

R_2 (Ω)	R_2 (measured)	V_{out}
10		
100		
470		
1k		
2k		
10k		
47k		

The output voltage V_{out} is related to the input voltage V_{in} by the voltage divider equation

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in} . \quad (1)$$

Copy this equation down into your lab notebook. Note that $V_{out} \leq V_{in}$, regardless of the values of R_1 and R_2.

1. Take a 1 kΩ resistor from the resistor set. Using the Extech handheld digital multimeter (DMM), measure its resistance and record the value in your lab notebook. This resistor will be used for R_1 in the voltage divider circuit. Carefully, insert it into the proto board in the correct position.
2. Copy Table 1 into your lab notebook with a column for values of R_2 and a column for V_{out}.
3. Locate the first resistor R_2 in the set. Remove it from the bin. Measure its resistance and record the value in the table in your lab notebook.
4. Insert this resistor into proto board as R_2 to form the circuit shown above. Use the proto board's built-in power supply to provide V_{in} = 10 V to the circuit. Make sure the other end of the circuit is properly connected to ground.
5. Using the Keysight precision digital multimeter (DMM), measure V_{out} relative to ground and record the value in your table.
6. Remove the resistor R_2, straighten it out, and **put it back in the appropriate bin.**
7. Repeat steps 3 – 6 until you have cycled through the entire table of resistors.
8. Turn off the breadboard power supply. Disconnect power supply wires from breadboard.
9. Remove the resistor R_1, straighten it out, and **put it back in the appropriate bin.**
10. Make a plot of the *measured* output voltage V_{out} as a function of R_2 with the theoretical curve given by Eq. (1).

Part II: Non-ideal Power Supply

Any given power supply—whether it is a battery or the voltage source on the breadboard—has a finite limit on the amount of power that it can supply. This often results in unexpected behavior. In this exercise, you will see what happens when you try to draw more power from a battery than it is capable of producing.

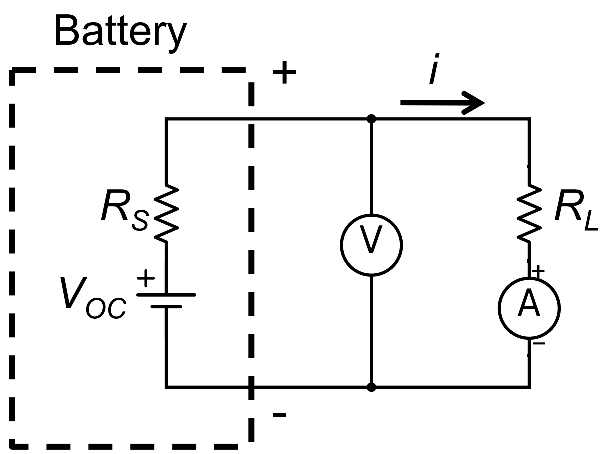


Figure 2 – A battery has an "internal resistance" R_S that limits how much power it can output. Engineers sometimes model it as and ideal voltage source V_{OC} in series with a resistor R_S.

Table 2

R_L (Ω)	R_L (measured)	V_{out}	i
0	N/A	0	i_{sc}
4.3			
5.1			
10			
15			
20			
30			
47			
100			
150			
∞	N/A	V_{oc}	0

1. Pull the coin battery and holder from the jar and insert it vertically into the breadboard, **such the pins are on separate rows**. Plug a breadboard jumper wire into each of the two rows.
2. Use the Keysight precision DMM to measure the raw battery voltage without any load resistor or ammeter connected to it. This value is called the "open circuit voltage". Record it in your lab notebook as V_{OC}.
3. Switch the Keysight precision DMM to the 3Amp, "DCI" ammeter mode. Switch the red cable to the 3A receptacle on the bottom right.
4. Connect the red and black mini-grabbers to the battery, count to 10, write down the current, and immediately disconnect. This is called the "short circuit current". Record it in your lab notebook as i_{SC}.
5. Use V_{OC} and i_{SC} to calculate the ***internal resistance*** of the battery $R_S = V_{OC}/i_{SC}$.
6. Switch the Keysight precision DMM back to "DCV" voltmeter mode. Move the red cable from the 3A receptacle back to the DCV receptacle.

7. Copy Table 2 into your lab notebook with a column for values of R_L, a column for voltage V_{out}, and a column for current i.
8. Locate the 150 Ω resistor in the jar. Measure its resistance and record the value in the table in your lab notebook.
9. Use this resistor as R_L to construct the circuit shown in Fig. 2. Use the Keysight DMM as the voltmeter. Note that the circuit elements within the dashed line are all ready *inside* of the battery, so you need not worry about them for now.
10. Use the Extech handheld DMM as the ammeter in the 200mA mode to measure current. Note that it forms a conductive path between the resistor and battery.
11. Record the current and voltage value you measure for the resistor in the table in your lab notebook.
12. Choose another resistor from the pile and repeat steps 9 – 11 until you have cycled through the entire jar of resistors. You should see the output voltage V_{out} decrease as more current is drawn from the battery. This phenomenon is known as "voltage droop".
13. Make a plot of the output voltage V_{out} as a function of the load resistance R_L.
14. Make a plot of the **power** $q_L = iV_{out}$ as a function of the load resistance R_L. Add a vertical line at $R_L = R_S$.

Data Analysis and Deliverables

Please make the following plots in Matlab, import them into a LaTeX or MS Word document, and give them intelligent, descriptive captions. In the captions, be sure to answer the questions posed in the deliverables. Make sure the axes are clearly labeled with units. Plots with multiple data sets on them should have a legend.

1. Plot your data from Part I, $\boldsymbol{V_{out}}$ **vs.** $\boldsymbol{R_2}$, with the theoretical voltage divider equation plotted on top. Be sure to mention the theoretical equation in your caption.
2. Consider the circuit shown in Figure 2. Using a pen or pencil and a sheet of graph paper, please do the following:
   a. Derive an equation for the battery current i as a function of V_{OC}, R_S, and R_L.
   b. Derive an equation for the battery voltage V_{out} as a function of V_{OC}, R_S, and R_L.
   c. Derive an equation for the power dissipated in the load resistor q_L as a function of V_{OC}, R_S, and R_L.
3. Using your data from Part II, plot $\boldsymbol{V_{out}}$ **vs.** $\boldsymbol{R_L}$, with the theoretical equation you derived in deliverable 2b for V_{out} on top of the data.
4. Using your data from Part II, plot the measured power $\boldsymbol{q_L}$ **vs.** $\boldsymbol{R_L}$ with a vertical line at $R_L = R_S$. Also plot, the theoretical equation you derived in deliverable 2c for q_L on top of your measured data.

Questions

Please answer the following questions in the captions of your plots.

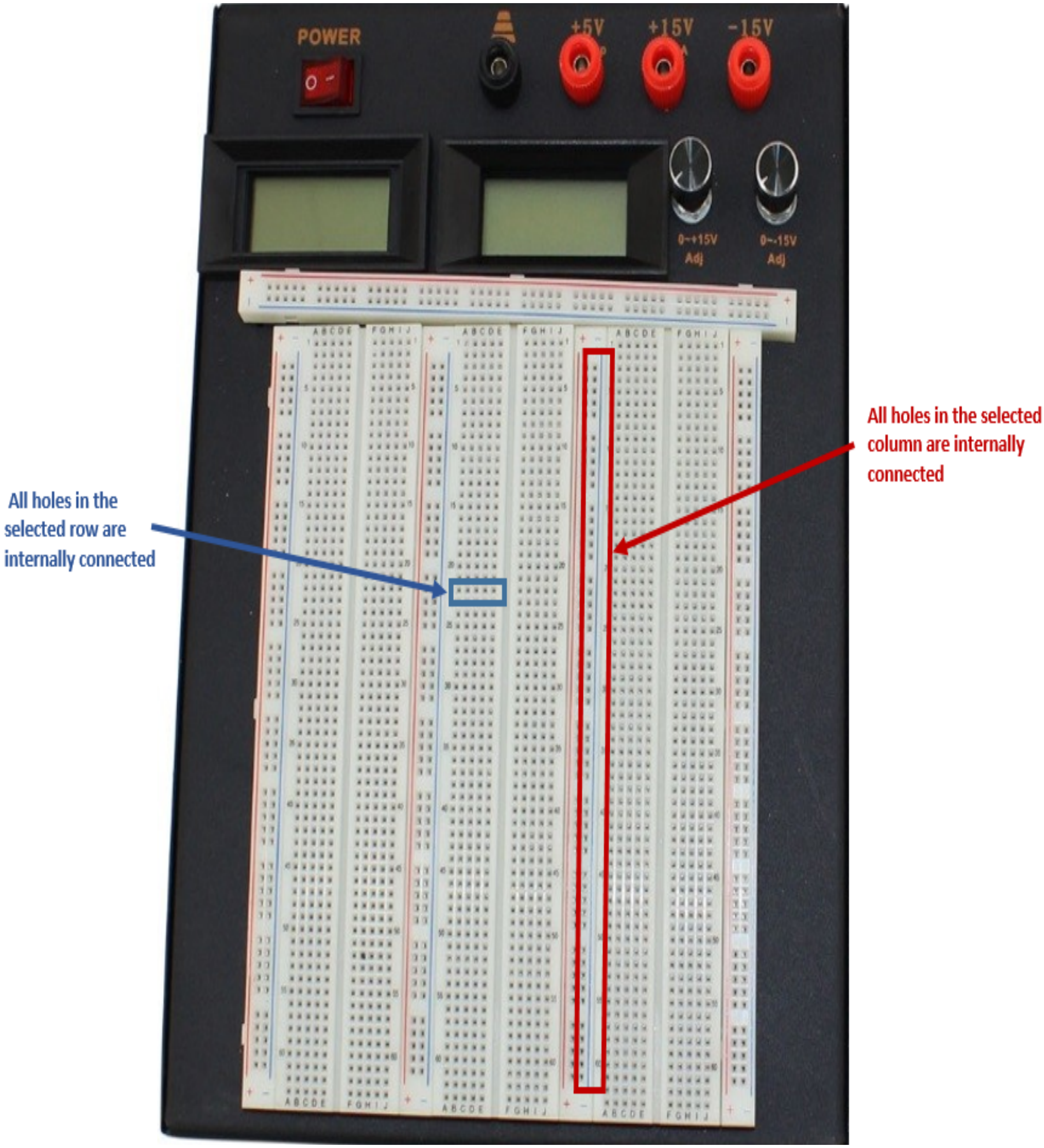
- Do a Google search of "impedance matching". Use this to explain your data from Part II.

Appendix A

Equipment

- Keysight 34465A Precision digital multimeter (DMM)
- Powered Breadboard
- Breadboard jumper wires
- Extech Handheld Multimeter (DMM);
- 4 - Banana to red /black minigrabber cable– 2’ or 3’ length
- 3V Lithium coin battery (CR2032) and holder
- BNC – BNC cable
- Jameco Resistor kit
- Jar of resistors with values listed in Table 2

Appendix B


POWER
+5V
+15V
-15V
0~+15V Adj
0~-15V Adj
All holes in the selected column are internally connected
All holes in the selected row are internally connected