Laboratory 7: Circuit Building and Measurements

Introduction

This lab focuses on using breadboards, variable voltage power supplies, resistors, and multimeters. By the end of the lab, you should be able to build a circuit as well as take resistance, voltage, and current measurements with a multimeter. You will also compare your results to those obtained via Tinkercad and MultiSim. There are several Pratt Pundit pages that support this assignment.

Equipment

For this lab, each group of two (or occasionally three) people will need an MS8264 digital multimeter with two test probes, a PBB 272 powered breadboard, five alligator clip patch cords (one each of red, yellow, black, green, and white), and seven wires (red, yellow, black, green, white, brown or orange, and blue or purple). You will also need three pairs of resistors, specifically two each of 1000 Ω, 2200 Ω, and 1 MΩ. All of these should be at your station when you arrive and a TA will check to make sure they are all at your station before you depart.

Safety

As with all labs, safety is paramount. The equipment you are using - specifically the powered breadboard - is capable of doing significant harm to yourself, to others, to itself, and to other equipment. You must always be aware of when it is on, the voltage levels of the adjustable supplies and any connections on the breadboards. The multimeter can also do serious harm - both electrically and physically. The latter comes into play because the ends of the probes are particularly sharp; the former because the multimeter does supply power through the probes and, if used incorrectly, can harm equipment or injure people.

Please note that if an instructor or TA sees a student acting actively or passively irresponsible, the student will be asked to leave the lab and will receive a zero for the assignment. Depending on the nature of the infraction, the case may also be submitted to the conduct board as a violation of the Duke Community Standard.

For labs involving electronics, please remove any jewelry, watches, bracelets, etc. from on or near your hands. Also note that you should have neither food nor drink nor any other extraneous thing on your lab bench. The more you can focus on the equipment, the better.

Assignment

For this assignment, you and your partner(s) will generate one lab report for the whole group. You can therefore collaborate with other members in your group, but should not discuss the lab with other groups. Each member of the group should turn in the same lab report and supporting documentation. During the lab, you will be filling out a Google sheet indicating who your group members are.

When you submit the lab, it should include the data tables, answers to the questions, a Maple worksheet, and any required screen-shots. The images can be incorporated into the main document or uploaded separately as long as you reference the filenames in your main document. The worksheet should be in both MW and PDF form.

A LaTeX skeleton is available on Sakai, though LaTeX is not required. However you create your document, be sure to indicate your lab section and the names and NetIDs of all the people in the group. Again, each person needs to upload the lab. Also, include the name and NetID of each group member in the text portion of the Sakai assignment (if it lets you).

7.1 Resistance Measurements

For the first part of lab, you will be taking measurements for your six resistors to validate the tolerances given by the manufacturer. As you take measurements, be sure to keep track of which resistor is which (i.e., find some nondestructive way to differentiate between the two resistors of the same nominal values). More information on using the multimeter in general is available at the Pundit page for the `MS8264`.

To use the multimeter to measure resistances, first gently connect the test leads to the multimeter, with the black lead going into the black COM terminal and the red lead going into the right-hand red terminal that is labeled, among other things, Ω. Next, affix a white patch cord to the end of the black probe lead and a green patch cord to the end of the red probe lead. Through you could just try to put the sharp probe ends in contact with the resistor leads, it is generally easier to use the clips for this. Finally, clip one lead to one side of the resistor and clip the other lead to the other side - it does not matter which side is which for these measurements.

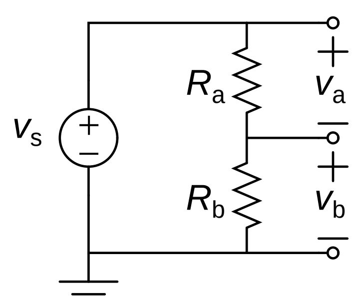
Now, turn the measurement dial on the multimeter to the most appropriate resistance scale. For example, the 1 MΩ resistors would require a range of at least 2M on the multimeter. While the 200M setting would work, the reading would have lower precision, so use the 2M scale. Once the dial is set, turn the multimeter on and take a reading. Once the value stabilizes, write it down in the resistance measurements data table. Later, you will calculate the measured tolerances to see if the resistors are within the manufacturers specifications.

Breadboard and Supply Connections

The PBB 272 has four binding posts and over 2000 pins arrayed on several individual breadboards. Information on how all these are connected is available on the Pundit page `PBB 272` - be sure to read that over before going to the next step. The connections for the first circuit will be explicitly given, but from there on out, it will generally be up to you to decide where and how to connect circuit elements. Note that the breadboards on the PBB are upside-down and the pictures on Pundit reflect this.[1] "Row 1" is thus at the bottom and the "Column A" for each pair of breadboard columns is on the far right of each pair.

7.2 Circuit 1: Voltage Divider

Now that you have both the nominal and measured values for resistance, you can build a circuit. During this lab, you will be building two circuits - one simple one for which all instructions will be provided and a second, slightly more complicated one you will need to construct on your own. The simple circuit is a voltage divider as follows:



where v_s will be set by the +15 V adjustable source and R_a and R_b will be a matched pair of resistors. Ideally, this voltage divider will split the voltage from the supply exactly in half.

7.2.1 Building the Circuit

To build the circuit start by selecting your 1 kΩ (a) resistor. Put one end in Col4-C10 and the other end in Col4-C6. Next, take your 1 kΩ (b) resistor and put one end in Col4-B6 and the other in Col4-B2. The two resistors are now in series because they share the Col4-ABCDE6 half row and nothing branches from there.

To connect the power supply - first, *make sure the PBB power switch is off and the two adjustment knobs are fully counter-clockwise.* Take the free end of the black patch cord connected to ground, clip in your black wire, and put the free end of the wire in Col4-A2. You have just grounded the "bottom" of the (b) resistor. Finally, take the free end of the red patch cord connected to the +15 V adjustable source, clip in the red wire, and put the end of the wire in Col4-A10. The circuit on the board is now the same as the circuit in the figure and resembles the left circuit of the Tinkercad image on the Pundit page for this lab.

[1] Someday I will fix this, but there are a few dozen screws per PBB to get this fixed, so...

7.2.2 Setting the Supply Voltage

Now you want to set the supply voltage. First make sure the multimeter is off. Turn the dial to the appropriate voltage measurement range keeping in mind that you want to measure approximately 10 V, then connect the wires connected to the clips from the multimeter to appropriate locations on the circuit; in this case, the white wire should connect to the bottom of resistor (b) at Col4-E2 and green should connect to the top of resistor (a) at Col4-E10. Now turn on the multimeter - you should be measuring close to 0 V. Turn on the PBB - you should still be measuring close to 0 V - if not, turn off the multimeter, turn off the PBB, make sure the voltage controls on the PBB are full counter-clockwise, fix your circuit if need be, and try again.

Once you are sure the PBB voltages are set to 0 V and the circuit is correct, turn on the PBB and the multimeter. Now rotate the positive voltage adjustment knob on the PBB until you are reading as close to 10.0V as you can get. If your PBB has voltage measurements on the PBB itself, ignore those - use the multimeter measurements. Note your multimeter reading in the data table for the voltage divider measurements.

7.2.3 Calculating and Measuring Voltage Divider Voltage Values

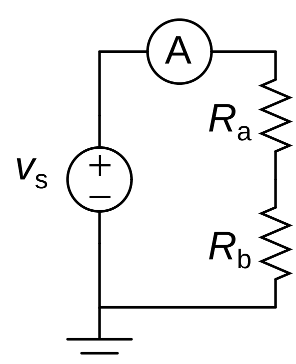
Use the actual source voltage measurement and the actual resistor measurements in the previous table to calculate what the voltage across each resistor in the bridge should be. Use the same precision as the voltage measurement device.

Now take voltage measurements across each resistor by connecting the green and white wires from the multimeter to appropriate locations on the breadboard and record these voltages in the data table. Note that some of the physical cables and wires that are white in real life are shown as gray in the Tinkercad pictures since white does not show up well in those images. Be sure to record these voltage measurements. For the nominally-1 kΩ resistors, the voltages should be close to 5 V for each so make sure your multimeter is set to the right DC voltage range.

7.2.4 Calculating and Measuring Current Values

Finally, you are ready to take a current measurement. Because the current measurement device must be placed in *series* with the branch in which you want to measure current, measurements of this sort are more disruptive to the circuit. This will be one of the *rare* times when you leave the adjustable voltage set to something other than zero when toggling the PBB power switch.

- Leaving the PBB voltage at its current...erm...present setting, turn off the power for the PBB.
- Next, *gently* remove the red probe from the right terminal of the multimeter and place it in the second red terminal - current measurements use the second and third ports versus the fourth and third ports of this multimeter.
- Calculate the current you expect for this pair of resistors given the source voltage measurement and resistor measurements and adjust then the multimeter measurement dial accordingly. Use the *measured* values of the two resistors for this calculation. The percent error in this case would thus be an error in measuring the current, not the error from differences between the measured and nominal resistances.
- Now comes the disruptive part - move the red wire from Col4-A10 and move it to Col4-A17. Now move the green wire connected to the positive multimeter port to Col4-C17. Finally, move the white wire connected to the negative multimeter port to Col4-A-10. Once again, the white wire is represented by a gray wire in the image. The circuit is now effectively



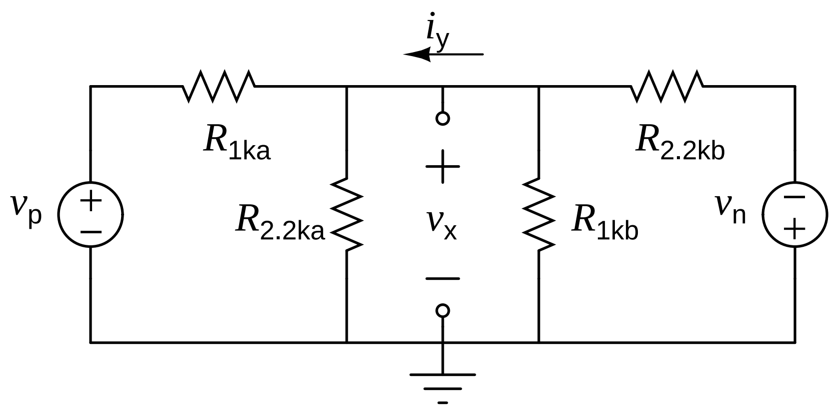
with the A representing the ammeter function of the multimeter.

- Finally, turn on the power supply, turn on the multimeter, and read the current flowing through the branch. Write this value in the appropriate space in the voltage divider current measurements table. If the current is too small to be measured, write "too small."

Having completed all these steps for the two 1 kΩ resistors, repeat them for the 2.2 kΩ resistors and the 1 MΩ resistors. Do you notice anything about the errors for the three pairs?

7.3 Circuit 2: Yours To Build

The following sections are based on the following circuit:



7.3.1 Analytical Solutions

Determine an appropriate Node Voltage Method equation (using smart labels, there will only be one equation) to find the unknown voltage. Use a Maple script to symbolically calculate v_x as a functions of v_p, v_n, and the four resistors, then use *that* to find a symbolic expression for i_y. Substitute in your measured resistance values and assume v_p is 6 V and v_n is 4 V (meaning the top right node is at -4 V) to numerically calculate v_x and i_y. You should have a TA come by to check your values.

7.3.2 Building the Circuit

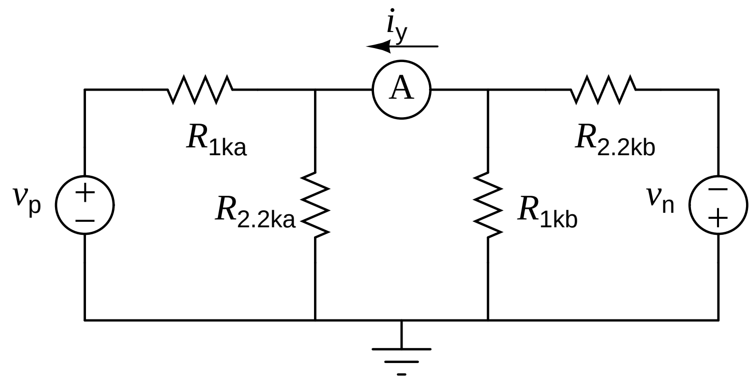
Next, build the circuit on the breadboard using the red V+ lead for the wire connected to the positive terminal of v_p and the yellow V- lead for the wire connected to the *negative* terminal of v_n. Just be sure the PBB power switch is off while building the circuit. Note that the black wire connected to the black patch cord connected to the PBB ground is effectively the negative terminal of the v_p source and also the *positive* terminal of v_n source - it therefore represents the bottom, negative terminal of v_p as well as the bottom, positive terminal of v_n. The red wire connected to the red patch cord connected to V+ represents the top, or positive terminal, of v_p in the circuit drawing. The yellow wire connected to the yellow patch cord connected to V- represents the top, or *negative* terminal, of v_n in the circuit drawing. You will want to build the circuit in two halves - the *a* side and the *b* side - and then connect them with the brown (or orange) wire between the junction connecting the *a* resistors and the junction containing the *b* resistors. This is because, eventually, you will want to measure the current through that wire and the only way to do that is to put the multimeter in series with that wire. You will also use a blue (or purple) wire to connect the bottom of the left side to the bottom of the right side. There is a picture of a Tinkercad model of this circuit on Pundit.

7.3.3 Measuring v_x

Once the circuit is built, make sure the multimeter is in voltage measuring mode (the red patch cable inserted in the far right port on the multimeter and the dial set to measure DC voltages). Turn the PBB switch on and use the multimeter to guide you in adjusting the positive and negative voltages to the values given in the circuit - again, do not rely on the digital readouts from the PBB if yours happens to have them. Once the source voltages are set, use the multimeter to measure v_x. You should have a TA come by to check your measurement; it should be quite close to what you calculated earlier.

7.3.4 Measuring i_y

Next, determine a way to build the circuit so that you can measure i_y. Leave the voltage adjustments set but turn the PBB off. You will need to disconnect the wire going between the junction of the *a* resistors to the junction of the *b* resistors and put the multimeter in series with that wire. Effectively, you will have the following circuit:



Before you turn on the PBB, be sure to change the multimeter so that it can measure current - move the red patch cable back to the current (second) port and set the dial to measure DC currents. Turn the PBB on and take the current measurement. You should once again have a TA come by to check your measurement, and once again, it should closely match your calculations.

7.4 Simulations

7.4.1 MultiSim

Using MultiSim, "build" this circuit, including a single V/A probe to measure the voltage v_x and the current i_y. Be sure the current measurement is facing in the right direction. Record the values of both the voltage and the current and also save an image of the schematic - take the picture while the system is running interactive mode so the probe values appear in the shot. **Note:** if you feel as if you have built the circuit correctly but the current seems off: save the circuit, close MultiSim, open MultiSim, and re-open your circuit. There is a strange bug we are trying to track down that sometimes measures the wrong current depending on where on the wire you measure, but it goes away with saving and reloading.[2]

7.4.2 Tinkercad

Using Tinkercad, "build" this circuit, then include both a multimeter to measure the voltage v_x and another multimeter to measure the current i_y. You circuit will be different from the ones on Pundit because you have have two multimeters (one for voltage and one for current) in the *same* circuit rather than two different circuits with one multimeter each. Record the values of the voltage and current and also take a snapshot of this circuit being simulated, meaning the measurements should be showing up on the multimeters (with the bonus that the current through the courses will also be known).

[2]And by "we," I mean I sent the folks at NI a picture of things going wrong and said, "This is not good," and they replied, "That is not good, but also, we can't get that to happen."

7.5 Data Tables and Calculations

7.5.1 Resistance Measurements

- Resistance measurements and tolerances

Resistor	Color bands	Nominal Tolerance	Measured Value	Measured Tolerance
1 kΩ (a)				
1 kΩ (b)				
2.2 kΩ (a)				
2.2 kΩ (b)				
1 MΩ (a)				
1 MΩ (b)				

where measured tolerance is given by:

$$\left|\frac{\text{measured} - \text{nominal}}{\text{nominal}}\right| \times 100\%$$

7.5.2 Voltage Divider

For the simulated voltages and currents in the next two tables, go back and use the divider you made for Lab 2 in Tinkercad and replace the resistors with the values you measured in lab for each of the three pairs. For the voltages, use only one simulated multimeter: take the measurement across the top resistor and record that value, then take the measurement across the bottom resistor. Do not try to take both measurements at once as that will not accurately simulate the actual procedure used in lab. You do not need to include the Tinkercad schematics in your report, just the results.

- Voltage divider voltage measurements using measured resistor values
  Source voltage measurement: (should be very close to 10.0 V)

Resistor	Calc. Voltage	Meas. Voltage	Meas. % Err.	Sim. Voltage	Sim. % Err.
1 kΩ (a)					
1 kΩ (b)					
2.2 kΩ (a)					
2.2 kΩ (b)					
1 MΩ (a)					
1 MΩ (b)					

where percent error is given by:

$$\left|\frac{\text{measured or simulated} - \text{calculated}}{\text{calculated}}\right| \times 100\%$$

- Voltage divider current measurements using measured resistor values
  Source voltage measurement: (should be very close to 10.0 V)

Eq. Resistance	Calc. Current	Meas. Current	Meas. % Err.	Sim. Current	Sim. % Err.
2×1 kΩ					
2×2.2 kΩ					
2×1 MΩ					

Note: some (or, rather, one) of the current measurements may not be (is not) within the range of the multimeter; in those (that) cases (case), write "too small" or "too large" to indicate *how* the current is outside the range.

7.5.3 Circuit 2: Yours To Build

- Measurements from Circuit 2 - use measured resistance values to calculate and be sure your actual sources are very, very close to 6 V and (-)4 V, respectively.

Variable	Calc/Stated Value	Meas. Value	Meas. % Err.	MultiSim Val.	Tinkercad Val.
v_{p}	6 V			6 V	6 V
v_{n}	4 V			4 V	4 V
v_{x}					
i_{y}					

7.6 Questions and Conclusions

(1) Were all of your resistors within their stated tolerances?

(2) Was there anything not predicted by simple voltage division with the voltage divider voltage measurements and simulations compared with the calculations? If so (and there better have been), what was it? Why do you think that happened?

(3) Based on the above information, what do you think is the internal resistance of the multimeter you used? [3] Include a clear set of calculations in finding this estimate and reference your conclusions from Lab 2 regarding what kind of resistor values are most likely to yield useful results when calculating the internal resistance of a voltmeter.

(4) For the voltage measurement of Circuit 2, and based on the Tinkercad schematic on Pundit, the green wire from the multimeter is in Col3-G6. What are all the possible other pins that wire could be in to get the same voltage reading (without changing any other connection)?

(5) For the current measurement of Circuit 2, and based on the Tinkercad schematic on Pundit, the gray (white)[4] wire from the multimeter is in Col3-G6. What are all the possible other pins that wire could be in to get the same current reading (without changing any other connection)?

(6) Is there anything you can think of that would make it easier to build a circuit given a circuit diagram? What alterations would you make to this lab and its supporting documentation to make it more informative?

[3] And do you think this was too much of a hint for the answer to the previous question?
[4] Gandalf!

7.7 Final Notes

For Spring 2022, groups should produce a single lab document for the group, but *each person* in the group needs to upload the document to Sakai along with the MultiSim snapshot (showing the voltage and current measurements on the V/A probe in Circuit 2), the Tinkercad snapshot (showing the voltage and current measurements in on two different multimeters in Circuit 2), and the Maple worksheet solving for v_{x} and i_{y} symbolically and numerically. The snapshots can also be incorporated into the lab document rather than having separate files.