Strain gauge lab

In this lab, you will make measurements of mechanical strain in small aluminum beams as you bend them.

The strain gauge

The strain gauge is nothing more than a resistor whose value changes when it is elongated or compressed. When elongated, the thin wires which make up the strain gauge are elongated and the resistance goes up. When compressed the wires get shorter and fatter and the resistance goes down. When a strain gauge is stretched, its resistance changes according to the following formula

$$\frac{\Delta R}{R} = G_F \epsilon$$

where G_F is the gauge factor (it is 2.1 for our sensors), ϵ is the mechanical strain, R is the starting resistance (120 ohms in our case) and ΔR is the change in resistance. Since strain is usually quite small, the change in resistance is also quite small. The mechanical strain is defined as the change in length of an object when a force is applied divided by the length with no load. To measure the small changes, we need a circuit with an output close to zero with no strain, and a high gain to amplify the change in resistance to a reasonable value which can be read by the DAQ.

Measuring the change in resistance

The classic circuit for measuring the resistance change is the Wheatstone bridge, shown below in Figure 1. In our case, the nominal resistance of the strain gauge is 120 ohms, so we show an example bridge with these values. If all the resistances are precise, and the variable resistance is adjusted to exactly 5 ohms, the bridge is balanced (all four resistors are equal) and you measure 0 volts. If the resistance of the strain sensor then changes, a slight voltage difference is measured at V_{meas} which is related to the resistance change of the strain gauge.

The variable resistor (potentiometer) is used to manually balance the bridge. Since resistors have some error, this variable resistor can manually set the equilibrium, no load condition to 0 measured voltage difference. Once balanced, we can sense small changes in resistance at the strain gauge. The voltage difference from the Wheatstone bridge (due to the change in resistance) is very small and must be amplified. To amplify the measured voltage we will use the instrumentation amplifier.

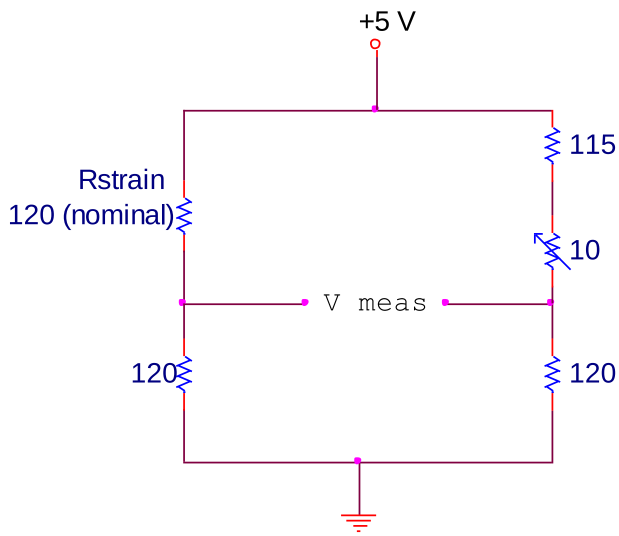


Figure 1: Classic Wheatstone bridge for sensing small changes in resistance

We will start by building the basic circuit, not with the strain gauge, but the 120 ohm resistor instead. Build the circuit below using the same instrumentation amplifier as last week.

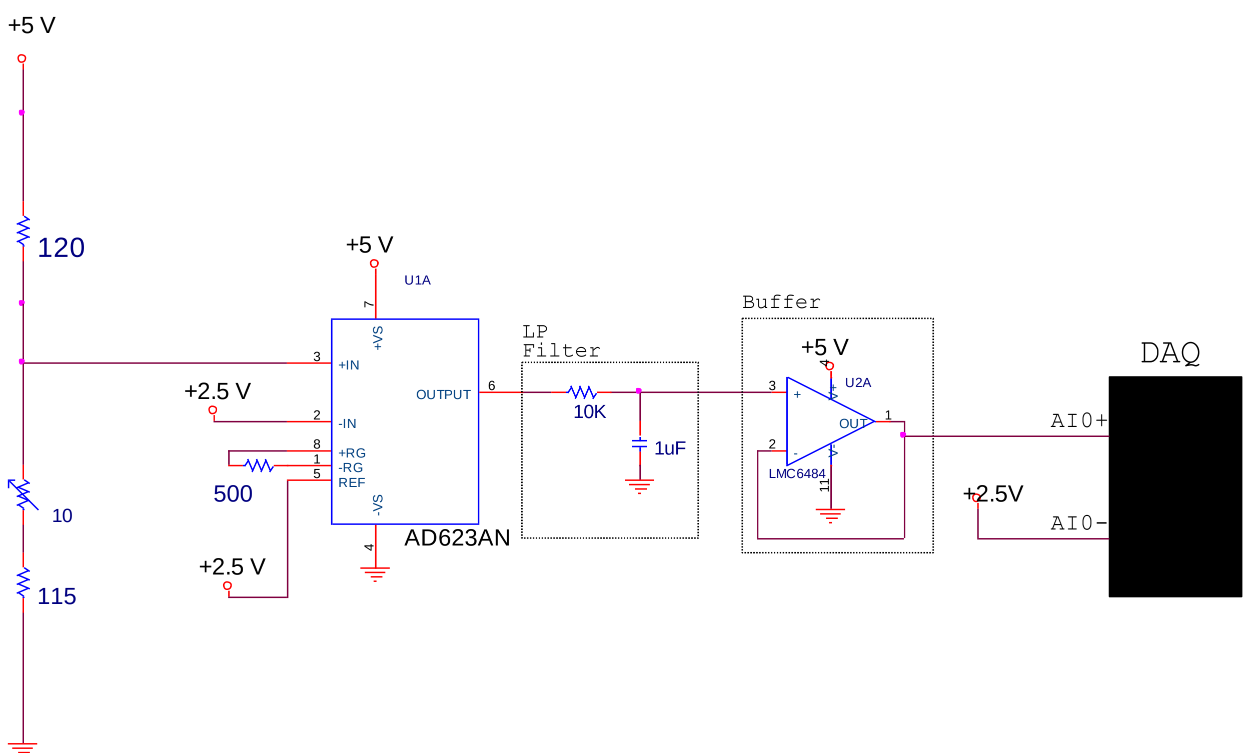


Figure 2: First circuit to build. The 120 ohm resistor in the upper right branch of the bridge is the stand-in for the strain gauge. Note that the left side of the classic bridge circuit only provides a 2.5 V reference, so we just use the available 2.5 V reference.

Once you have the circuit built, run the program used in the EKG experiment that displays the measurements in real time. As the program runs, turn the potentiometer to balance the bridge (set the measure value at ai0 to zero volts) as best you can. It is a 25 turn potentiometer, so it may take several turns to get it unstuck from one of the rails. It is also not crucial that it is perfectly zero, in fact it is likely to jump a little when you take the screwdriver off the potentiometer.

Once the bridge is balanced, add a 100K resistor in parallel to the 120 Ohm resistor which is the stand-in for your strain gauge. The 100K resistor in parallel with the 120 ohm resistor makes the resistor in the upper right branch of the bridge have an effective resistance of 119.856, a change of 0.1438 Ohms. Run the program, as it is running pull the 100K resistor out of the circuit. You should see a sudden change when you pull the resistor.

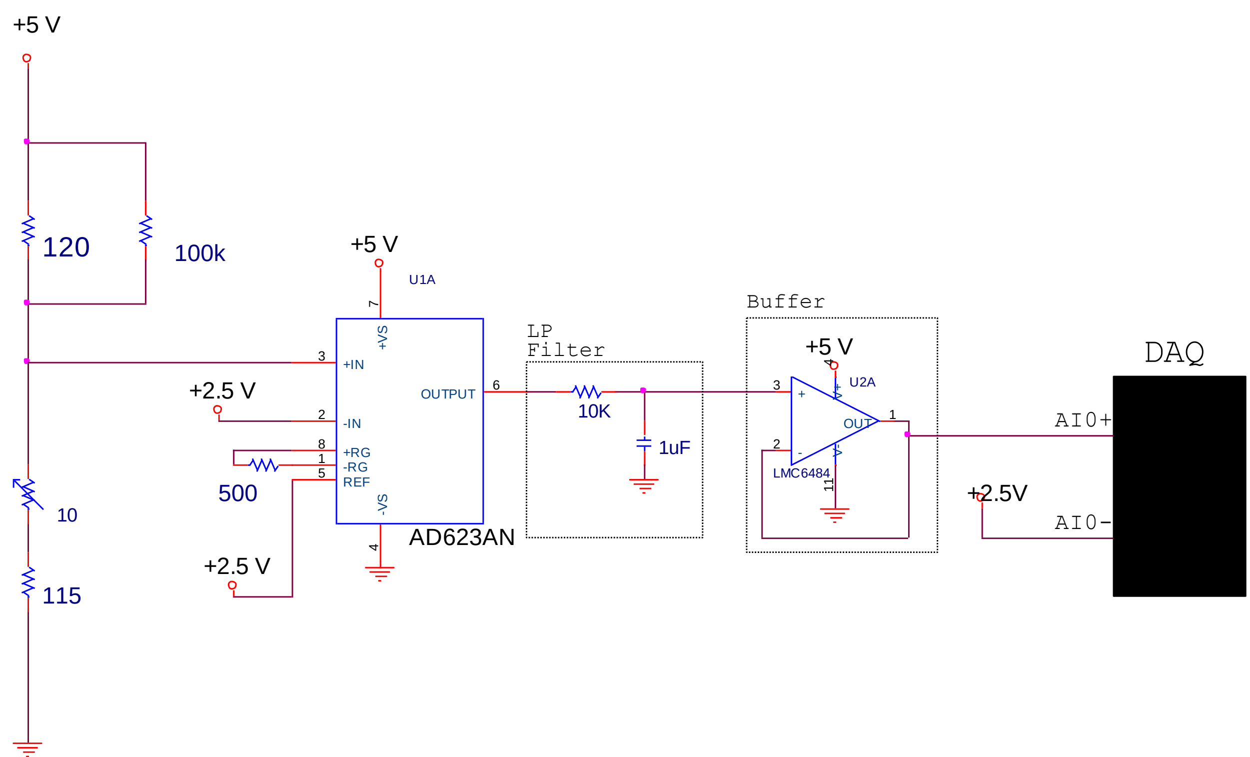
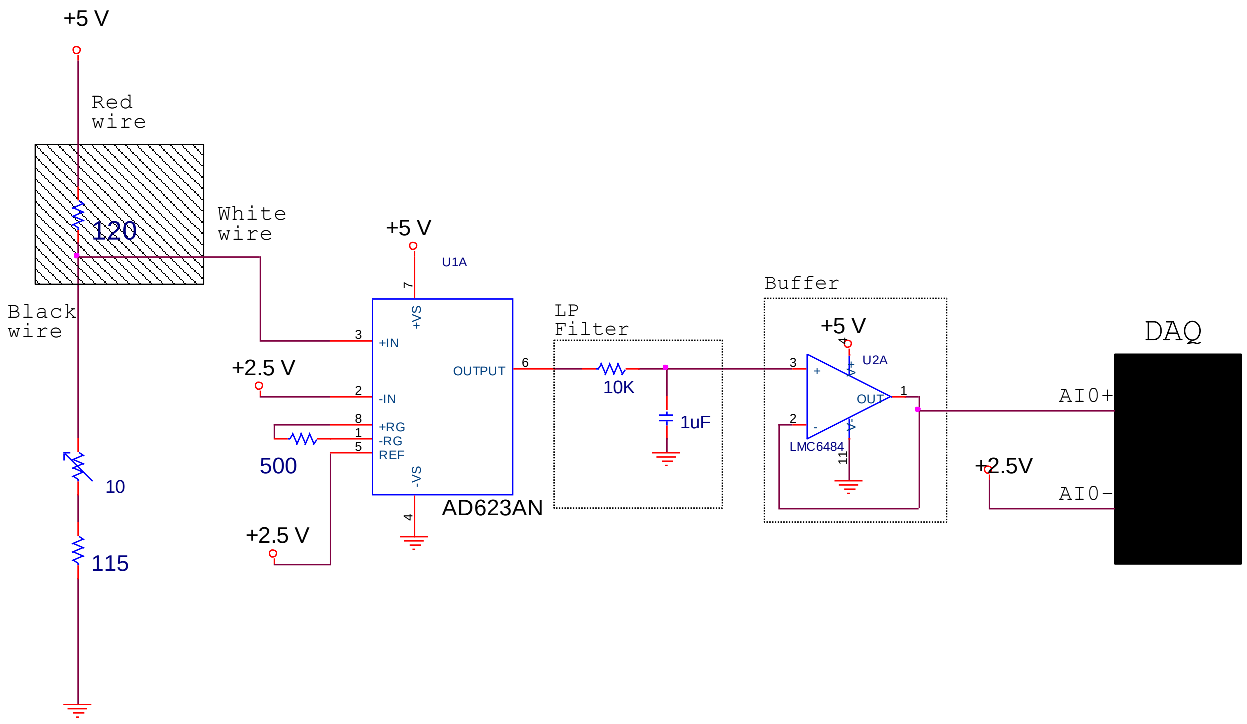


Figure 3: Second circuit. The 100K resistor in parallel with the 120 ohm resistor simulates a small change in the resistance, to 119.85 ohms.

Derive an expression for the voltage that you measure at the DAQ to change in the resistance of the upper right branch of the bridge circuit. Compare this result with what you measured. You should get excellent agreement. Repeat the experiment with a 1M resistor instead. See if everything still works as expected. Can you accurately sense this change in overall resistance?

Now replace the 120 ohm resistor with the strain gauge. These are 3-wire measurements which is a special arrangement which reduces error in the measurement due to changes in the resistance of the wire leads from the sensor to your circuit board. You can find a description of the 3-wire arrangement here:

http://zone.ni.com/devzone/cda/tut/p/id/3642



Follow the directions on the website to mount the strain gauge to a small beam. Cantilever the beam using a bar clamp to the edge of your desk. Run your program and re-balance the bridge by adjusting the potentiometer with the screwdriver. Once it is balanced, try pushing on the end of the beam with your finger and you should see the voltage change. Push up and it should change in the other direction. Flick it and you should see damped oscillations. When you unload the beam, the signal should return to zero. Note that it is probably impossible to perfectly balance things. This is fine. It is really only the change that is important anyway.

Once this is working, run the program and hang successively more weights on the hook. As you add weight, the voltage should continue to change. You will probably notice that the signal oscillates while the weights settled, either due to the beam bouncing or the weights swinging.

Now, you will create a calibrated scale. Setup the program to run for about 5 seconds. Start with the beam unloaded. Collect the data and record the mean value of the output voltage over that time period. Add 1 weight. Collect the data and take the mean value. Add a second weight, and so on. Continue up to 5 weights. Then continue, but this time removing the weights one at a time. If everything is great, you will get the same value on the way up as the way down. Reorder your weights and repeat for a second trial. Create a scatter plot of all your data of mass in grams versus change in voltage of the output (subtract off the unloaded value). Plot your data and a best fit straight line (see the command polyfit in MATLAB). Comment on how well it seems your scale is working – i.e. how repeatable, accurate? Based on your sensitivity, how small a change in mass do you think you can accurately sense? How large a mass can you sense before the device saturates?

Now plot the same data, but plotted as mass on the x-axis and measured strain on the y-axis. Use the gauge factor of 2.1 to convert from change in resistance to strain. Plot the expected result based on the equation given in the lecture. You don't need to know where this formula comes from.

Deliverables:

Things that should be part of your lab report are:

1) An analysis of the circuit that provides a relationship between the measured voltage at the DAQ to the change in resistance on the bridge.
2) A comparison of this analysis to the measurement with the 100K and 1M resistor in parallel. Comment on how a small a resistance change you can sense with this circuit.
3) A graph of all your data with the weights plotted as mass versus measured voltage. You should have a straight line fit through your data. State the sensitivity.
4) A graph with strain as a function of mass. This plot should compare the theoretical result provided in lecture.
5) Some commentary on your results addressing the questions in the lab about accuracy, sensitivity, etc.

Grading

10 points for everything above and correct

1) 2 points total for deliverable 1.
    a. 1 off if derivation is incorrect, but a reasonable effort.
2) 1 point total for deliverable 2, i.e. data matches your expected result.
3) 4 points total for deliverable 3
    a. 3 points off if you took data, but the data looks poor, too scattered, or not repeatable.
    b. 2 points off if data looks OK, but incomplete (i.e. not enough data points).
    c. 1 point off if data looks fine, but plot is not well-labeled, no axis, no units, etc.
4) 2 points for deliverable 4
    a. 1 point off if data is OK, but theoretical result is bad.
    b. 1 point off if data looks fine, but plot is not well-labeled, no axis, no units, etc.
5) 1 point total. Full credit for correct, concise, clear answers.