ENGR 1121 Lab 3
Strain Gauge

February 10, 2014

In this lab, you will make measurements of mechanical strain in a small cantilevered aluminum beam using a strain gauge as you bend it.

The Strain Gauge

The strain gauge is nothing more than a resistor whose value changes when it is stretched or compressed. When stretched, the thin wires that make up the strain gauge are elongated and thinned 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 (2.1 for our sensors), ϵ is the mechanical strain, R is the nominal strain gauge resistance (120Ω in our case) and ΔR is the change in resistance due to the strain.

Because 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 Analog Discovery.

Measuring the Change in Resistance

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

Unfortunately, real resistors come with finite tolerances (e.g., ±1% for most of the resistors we use) and their nominal values are not always those we would like to use (e.g., the closest standard value for 1% resistors to 120Ω is 121Ω). Consequently, we typically add a variable resistor (a trim potentiometer or “pot”) to the bridge, as shown in Figure 1b, in order to balance it manually. To do so, we adjust the pot so that under a no load condition, the measured voltage difference is 0V. Once the bridge is balanced, we can sense small changes in resistance at the strain gauge. The voltage difference from the Wheatstone bridge (resulting from a change in the strain gauge's resistance) is very small and must be amplified. To amplify the measured voltage, we will use the instrumentation amplifier as we did in the ECG lab. In practice, we adjust the pot until the amplified voltage difference is 0V.

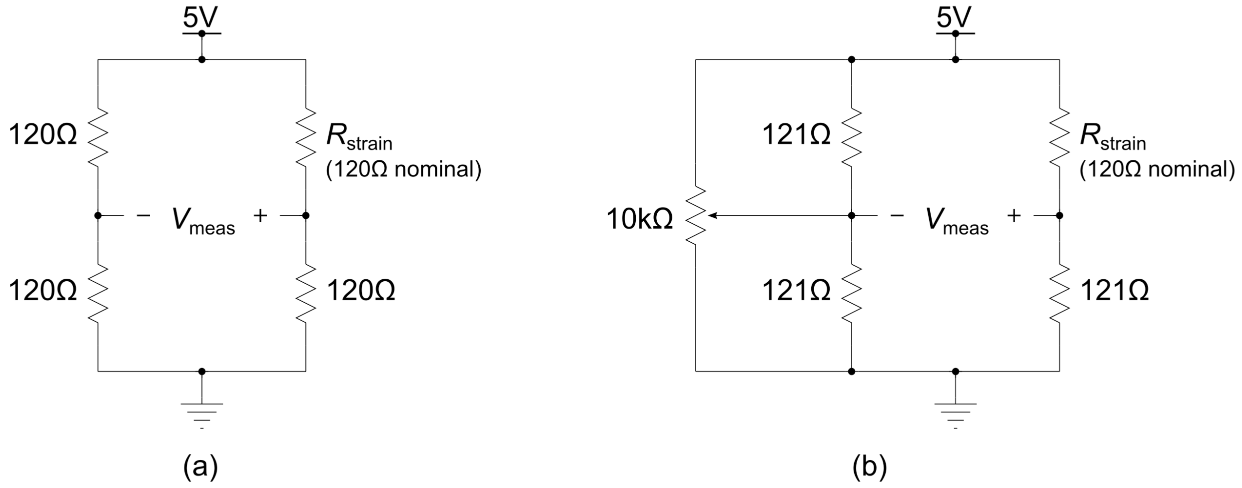

Figure 1. (a) Ideal Wheatstone bridge circuit with perfectly matched resistors whose values are the same as the nominal one of the strain gauge. (b) Practical bridge circuit with a trim potentiometer to balance the bridge compensating for resistor mismatch.

We will start by building the basic circuit, not with the strain gauge, but instead with a fixed 121-Ω resistor that will serve as a stand-in for the strain gauge. Build the circuit shown in Figure 2 using the same instrumentation amplifier and op amp as last week.

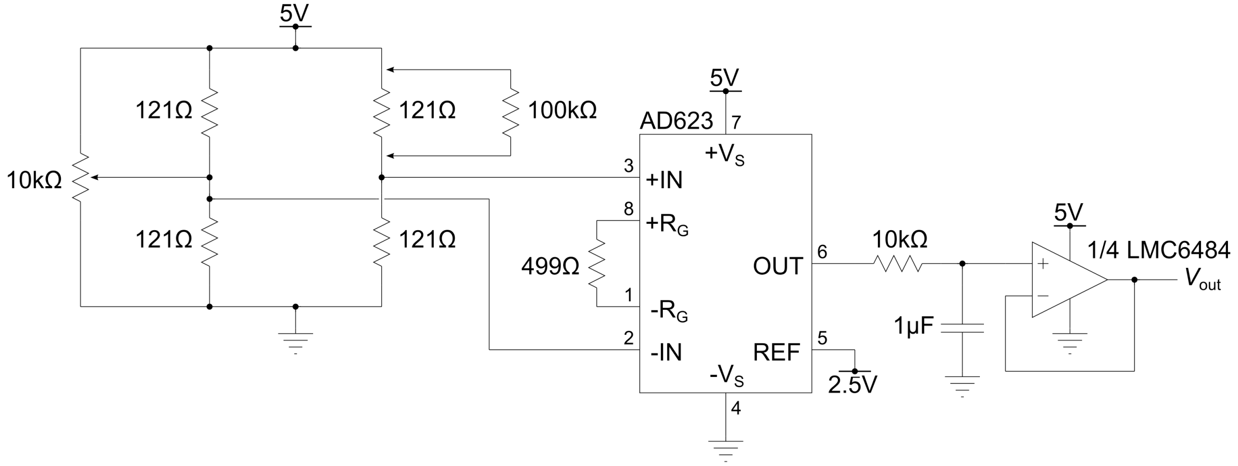

Figure 2. Initial bridge/amplifier circuit with a 121-Ω resistor standing in for the strain gauge. After balancing the bridge, you will add the 100-kΩ resistor and observe V_{out}.

Once you have the circuit built, observe the output voltage (measured relative to 2.5V) with one of the oscilloscope channels of the Analog Discovery. Adjust the potentiometer to balance the bridge (i.e., set the measured output voltage to 0V) as best you can. It is also not crucial that it is perfectly zero, in fact it is likely to jump a little when you take your finger off the potentiometer dial. Once the bridge is balanced, add a 100-kΩ resistor in parallel with the 121-Ω resistor that is the stand-in for your strain gauge, as shown in Figure 2. The 100-kΩ resistor in parallel with the 121-Ω resistor makes the resistor in the upper right branch of the bridge have an effective resistance of 120.854Ω, a change of 0.1462Ω. Acquire data from the Analog Discovery, as you pull the 100-kΩ resistor out of the circuit. You should see a sudden change when you pull the resistor.

Derive an expression for the voltage that you measure at the output of the circuit for a given 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 1-MΩ resistor instead of the 100-kΩ resistor. See if everything still works as expected. Can you accurately sense this change in overall resistance?

Now replace the fixed 121-Ω resistor with the strain gauge, as shown in Figure 3. These are 3-wire connection, which is a special arrangement that 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 at

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

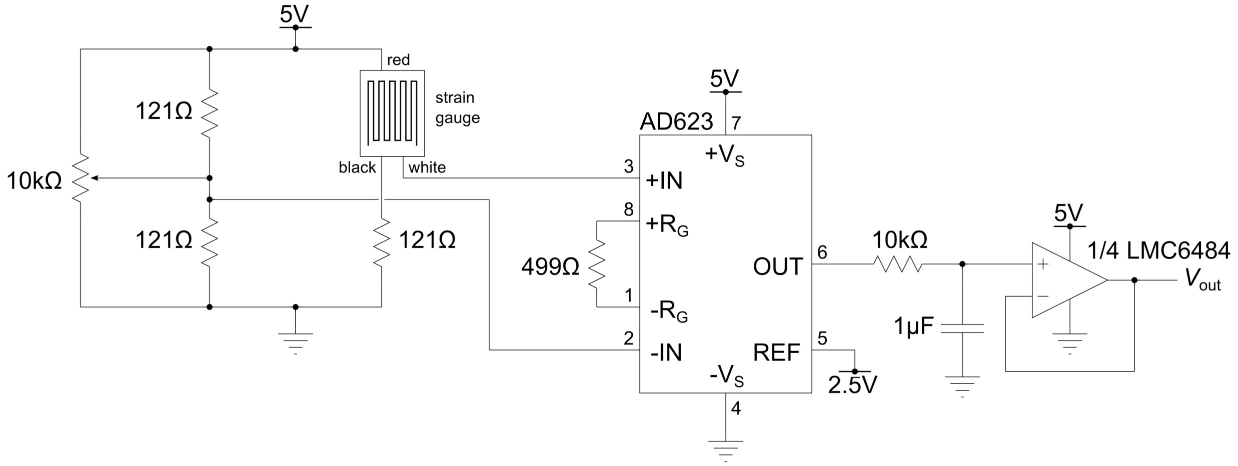

Figure 3. Final Wheatstone bridge/amplifier circuit with the strain gauge connected.

Get one of the beams with the strain gauge already mounted on them. Check the quality of the connections (both electrical and mechanical). If there are not enough beams with good gauges attached, follow the directions on the website to mount a new strain gauge to a small beam. Cantilever the beam using a bar clamp to the edge of your desk. Rebalance the bridge by adjusting the potentiometer. 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. That is fine. It is really only the change that is important anyway.

Once this is working, run the program and hang try hanging some weights on the hook. You will probably notice that the signal oscillates while the weights settled, either due to the beam bouncing or the weights swinging.

Once this is all working, you will work to create a calibrated scale. The first step is to add a long time constant low pass filter to your circuit. This filter will allow you to easily measure an average weight which will smooth out the swaying of the weights and remove all electrical noise. Select your filter to have a time constant of about 1 second or more. Select appropriate R and C values. Place your filter after the existing buffer. Add a second buffer after your new filter. Observe the output of the second buffer with your other Analog Discovery oscilloscope channel. You will now simultaneously measure the signal after the first lowpass filter and after the second one. If you suddenly load the beam you should see the signal on the first channel respond immediately, whereas the signal on the second one will take longer to respond. If you leave a weight on for a while, the two signals should agree.

Acquire data from the Analog Discovery scope 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. Be sure to record the actual mass of the weight you add each time. Once you reach five weights, begin removing the weights one at a time. If everything is working well, you will get the same value on the way up as the way down. Do a second trial with your weights reordered. 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 (e.g., how repeatable and accurate is it?) 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?

Deliverables:

Things that should be part of your lab report are:

1) An analysis of the circuit that provides a relationship between the measured output voltage and the change in resistance on the Wheatstone bridge. This analysis is at DC and does not need to account for the presence of the filters.
2) A comparison of this analysis to the measurement with the 100-kΩ and 1-MΩ resistor in parallel. Comment on how a small a resistance change you can sense with this circuit.
3) A single plot of circuit output as a function of time as you add one weight instantaneously. This plot should show the two simultaneous measurements after each of the two filters. Comment on the R and C values selected for the averaging filter.
4) A single 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.
5) Some commentary on your results addressing the questions in the lab.

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) 1 point for deliverable 3. R and C values are reasonable.
4) 5 points total
    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.
5) 1 point total. Full credit for correct, concise, clear answers.