

## Strain gauge lab

In this lab, you will make measurements of mechanical strain in small aluminum beams as you bend them. We will also work with our first integrated circuit component on the breadboard, the instrumentation amplifier.

### The strain gauge

The strain gauge is nothing more than a resistor whose value changes when it is elongated or compressed. When elongated, the small wires which make up the strain gauge get longer and thinner 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

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

where  $G_F$  is the gauge factor (it is 2.1 for our sensors),  $R$  is the starting resistance of the strain gauge ( $120\ \Omega$  in our case),  $\Delta R$  is the change in resistance,  $\Delta L$  is the local change in the length of the material, and  $L$  is the initial un-stretched length. The ratio of lengths is known as the mechanical strain. Since strain is usually quite small, the change in resistance is also quite small. Strain is a normalized measure of how much the material deforms.

### Measuring the change in resistance

The classic circuit for measuring resistance change is the Wheatstone bridge, shown below in Figure 1 (left). In our case, the nominal resistance of the strain gauge is  $120\ \Omega$  when no load is applied. If all the resistances are precise, the bridge is balanced. At the midpoint between the resistors on the left and right branch, the voltage is 2.5V on each side. Thus, when you measure the difference,  $\Delta V_{meas}$ , you see 0V at no mechanical load. If the resistance of the strain sensor then changes, you would measure a slight voltage difference across  $\Delta V_{meas}$  which is related to the resistance change of the strain gauge.

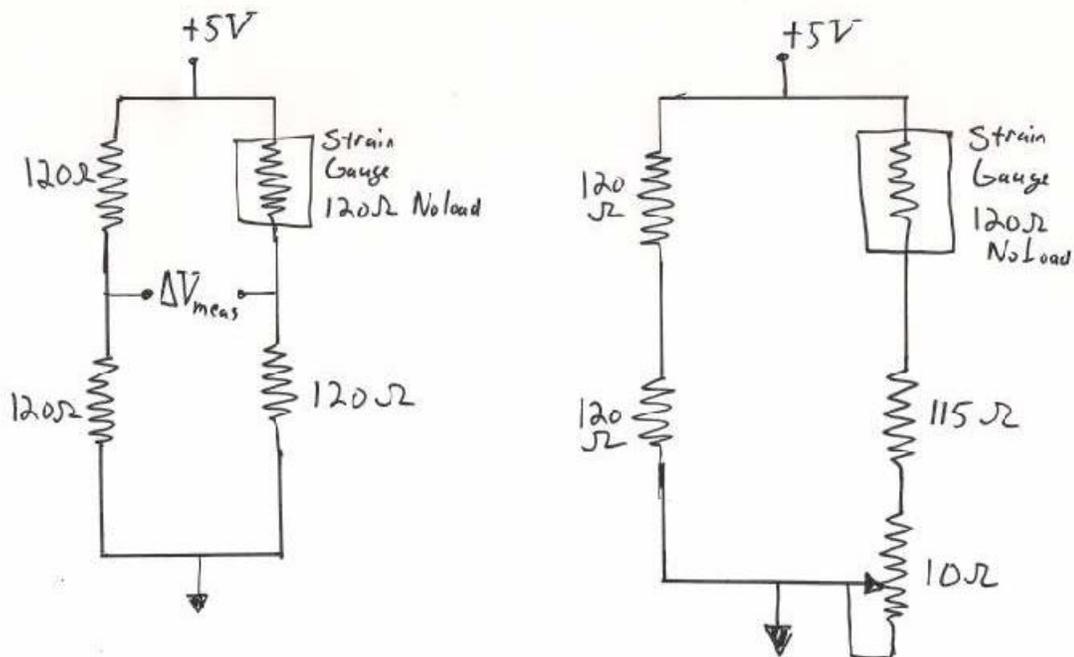
Unfortunately, real resistors come with finite tolerances (e.g.,  $\pm 1\%$  for most of the resistors we use). Consequently, we typically add a variable resistor (a trim potentiometer or “pot”) to the bridge, as shown in Figure 1 (right), in order to balance it manually. To do so, we adjust the pot 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. Notice that the potentiometer has three leads and we are only really using two of them to create a variable resistor. Recall the explanation of how the potentiometer works to understand how it is wired up.

We will start by building the basic circuit shown in Figure 2. Just to make your life confusing there are two types of strain gauges – the type doesn’t matter but the connection is slightly different for the two types. Sorry we bought a different parts on accident, and didn’t notice until time was too short to reorder.

- Some strain gauges we have 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. This arrangement is shown on the left in Figure 2. Here the black and white wire are attached to the same point in the actual strain gauge. **Depending on the exact model of strain gauge yours may have a red/gray and two gray wires. In that case the red/gray wire goes to 5V and the two gray wires can be used as white & black wire in Figure 2.**
- Some strain gauges are two-wire, which means they are just a simple resistor. That arrangement is shown on the right of Figure 2.

Note that the nominal resistor values are not always those we would like to use (e.g., the closest standard value for 1% resistors to  $120\Omega$  is  $121\Omega$ ). However, note that the value of the resistors on the left does not impact the circuit at all – we just pick similar values so the circuit diagram looks nice – really that’s it.

When you get one of the beams with the strain gauge already mounted on them - check the quality of the connections – both electrical and mechanical – before proceeding. If yours is defective give it to one of the instructors to put in the bin to fix.



**Figure 1: Classic Wheatstone bridge for sensing small changes in resistance. On the left is a classic bridge with perfectly matched resistors. On the right, we use a potentiometer to balance the bridge such that the measured voltage is 0 when the strain gauge is unloaded. This accounts for the fact that the resistors are not precise.**

Once you have the circuit in Figure 2 built, run the Analog Discovery to display the measurements in real time. Hook up channel 1 on the Analog Discovery to measure the voltage difference ( $\Delta V_{meas}$ ) across the two sides of the bridge. It should be pretty close to zero. Zoom in the y-axis scale on the

Scope to 50 mV per division. Adjust the potentiometer up and down. You should be able to control the voltage difference across the bridge to be around positive and negative 50 mV/division (that order of magnitude, anyway). If you are unable to make the voltage change by twisting the potentiometer – something is wrong. If you are unable to push the voltage difference both above and below zero – the system won't work. Once you are sure the circuit is working, balance the bridge and set the measured voltage to zero as best you can. It is not crucial that it is perfectly zero, in fact it is likely to jump a little when you take the screwdriver off the potentiometer.

Clamp the beam to cantilever off your desk where the strain gauge is **facing up and is just over the edge of the desk**. Push on the beam gently. Zoom your scope axis to be around 10 mV/division. When you push on the beam gently, you should notice changes on the order of a few mV.

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 make a better measurement. To perform the amplification, we will use an instrumentation amplifier, which we will discuss in lab how it works. In short, we will use this chip as a “black box” that takes a voltage difference and amplifies it by a large number on your breadboard.

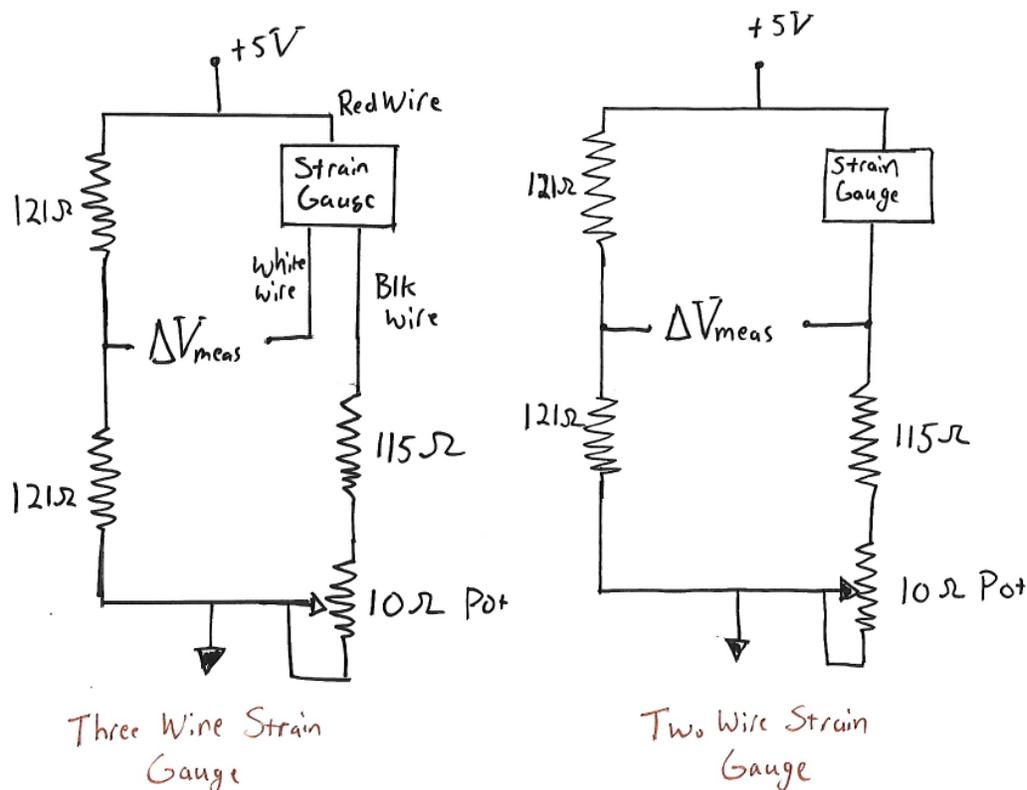


Figure 2: First circuit you should build to measure strain via the change in resistance. You will build either the left or right circuit depending on if you got a three or two wire strain gauge.

Build the circuit shown in Figure 3 (with slight modification if you are doing the two-wire measurement). Note the schematic uses a capacitor with a value of 100 picofarads (pF). We have

not discussed capacitors yet (next week). Here the capacitor only helps with noise and interference. The capacitor helps remove radio frequency noise, but does not influence the basic operation of the circuit. Once you have the circuit built, you will need to hook up the scope again. Plug channel 1 positive input into the output of the instrumentation amplifier and the negative input for channel 1 into the 2.5 V reference on your breadboard. Rebalance the bridge to zero (or close as you can get).

Once it is balanced, try pushing down on the end of the beam with your finger and you should see a nice voltage change. You will need to adjust the scope scale back to something like 1V/division. Push the beam 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 with the potentiometer. This is fine. It is really only the change that is important anyway.

Once you are happy that things seem to work, take some fishing line and tie a string to the end of the beam with the attached strain gauge. Add a paper clip “hook” to the end of the string. Note that you may need to balance the bridge by adjusting the potentiometer so that you have close to zero volts with no load. Take one of the large washers and load the beam while monitoring the voltage at the output of the instrumentation amplifier. You might see some oscillations as the system comes to rest. If the washer is swinging, the signal will show an oscillation at the frequency of the swing. If this is the behavior you observe, then everything is working great.

Now, take a series of washers. The washers have been weighed. Take a series of about 10 measurements (don't go above 300 grams) adding weights. Use the average (using the measurement feature in Waveforms) to make your measurements. Record the output voltage versus mass applied. When you have enough data you can make a plot of voltage change from the unloaded condition versus applied mass. The result should be very linear, and you should best fit a line through your data points as we did in week 1. This calibration line becomes your scale. Measure the voltage and you can now compute the mass from the calibration. **This final plot with your best fit calibration curve should be part of your lab report.**

**Analysis questions. Address these questions as part of your lab report:**

- Discuss your scales sensitivity and the relationship between measured voltage on the output and what is happening physically. For your circuit, a 20 mV change in the output voltage seems to be easily discernable. For a 20 mV change,
  - what is the associated change in electrical resistance of the strain gauge?
  - what is the mass that was applied to the scale to get this change?
- We argue above that in the strain gauge circuit, only the change matters – i.e. if the resistor values are not precisely known, then it doesn't matter. Work through the analysis of the example problem on page 22 of the book which addresses this question.

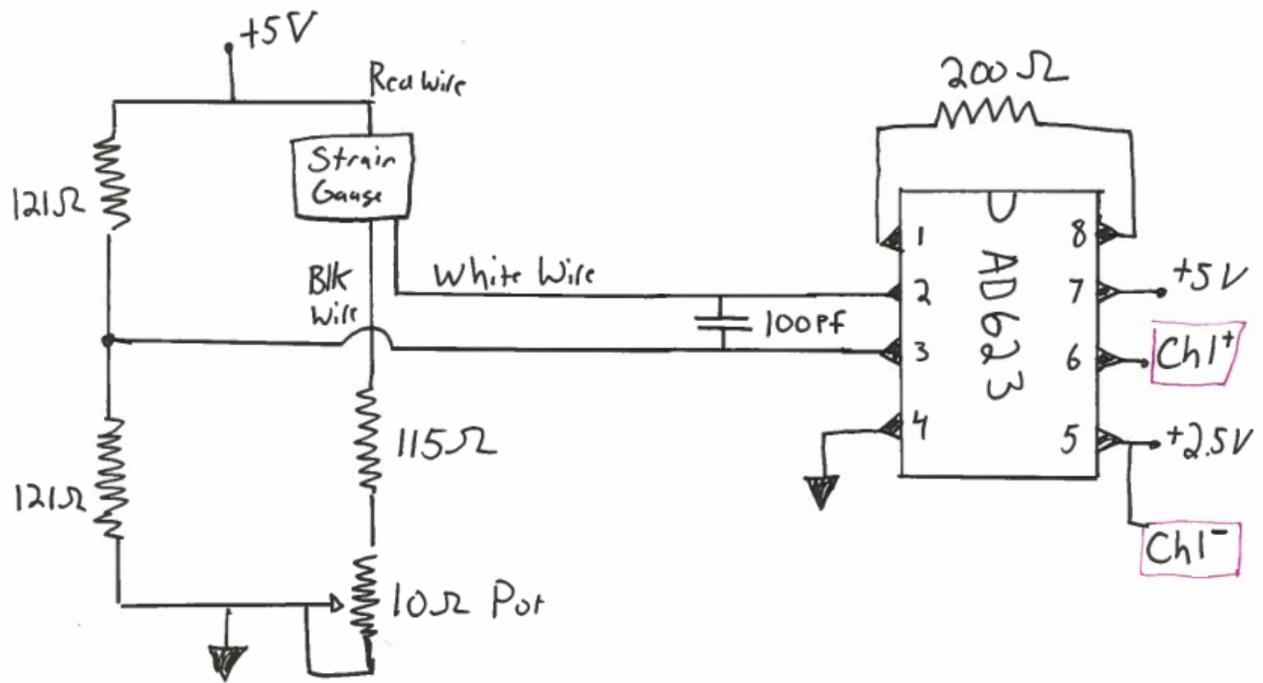


Figure 3: Final strain gauge circuit.