

Strain gauge lab – Part 1

In this lab, you will make measurements of mechanical strain in small aluminum beams as you bend them. We will continue this lab next week, so you will want to be careful to maintain your circuit so you can start where we leave off.

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 Ω in our case), ΔR is the change in resistance, ΔL 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 Ω 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 you see 0V at no mechanical strain. If the resistance of the strain sensor then changes, you would measure a slight voltage difference across V_{meas} , which is related to the resistance change of the strain gauge. We will have worked through this problem in class on Monday.

Unfortunately, real resistors come with finite tolerances (e.g., $\pm 1\%$ 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 120 Ω is 121 Ω). 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. 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 perform the amplification, we will use an instrumentation amplifier, which we will discuss in class.

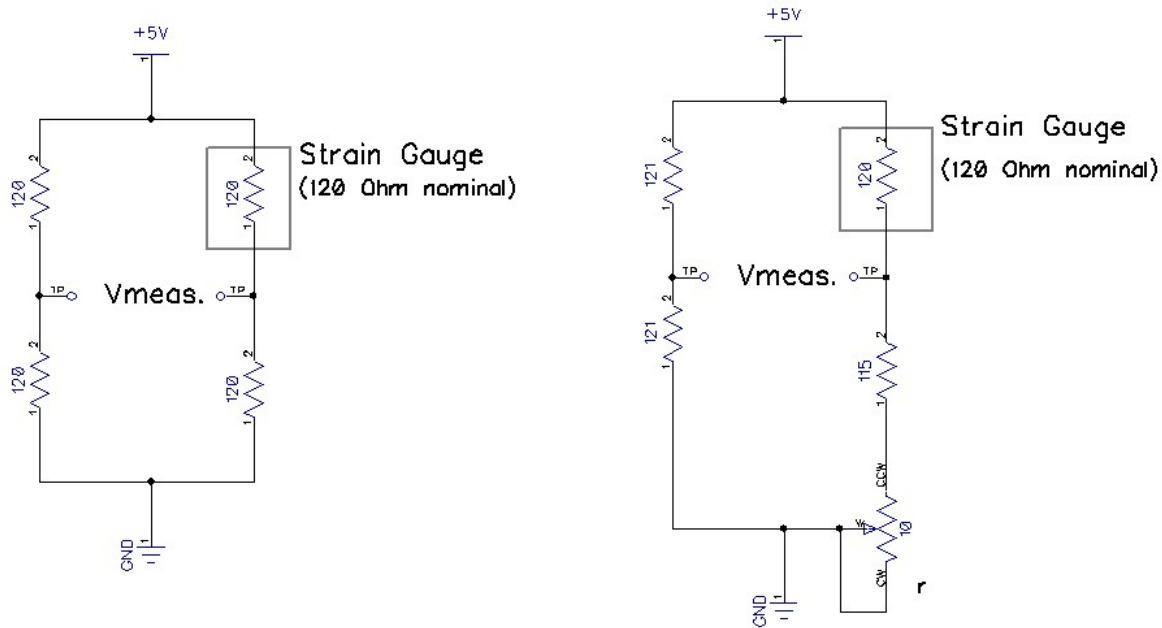


Figure 1: Classic Wheatstone bridge for sensing small changes in resistance. On the left is a classic bridge with perfectly matched resistors. On the right, we use a potentiometer to balance the bridge such that the measured voltage is 0 when the strain gauge is unloaded.

We will start by building the basic circuit, not with the strain gauge, but using a 121 Ω resistor instead. Build the circuit in Figure 2 on the left.

Once you have the circuit 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 (V_{meas}) across the two sides of the bridge. Adjust the potentiometer to 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.

Now leaving the Scope running, add the 10K resistor as shown on the right diagram in Figure 2. The 10K resistor in parallel with the 121 Ω resistor makes the resistor in the upper right branch of the bridge have an effective resistance slightly less than 121 Ω . Watch the Analog Discovery, as it is running put in and pull out the 10K resistor out of the circuit by hand. You should see a sudden change in voltage when you pull the resistor. This change is a stand-in for the small change in resistance of the strain gauge.

Try changing the 10K resistor to 100K and see if you can still measure the change in voltage from the original state. Note that the use of the 10K and 100K resistor here is to simulate the small changes in resistance we need to sense when we use the actual strain gauge.

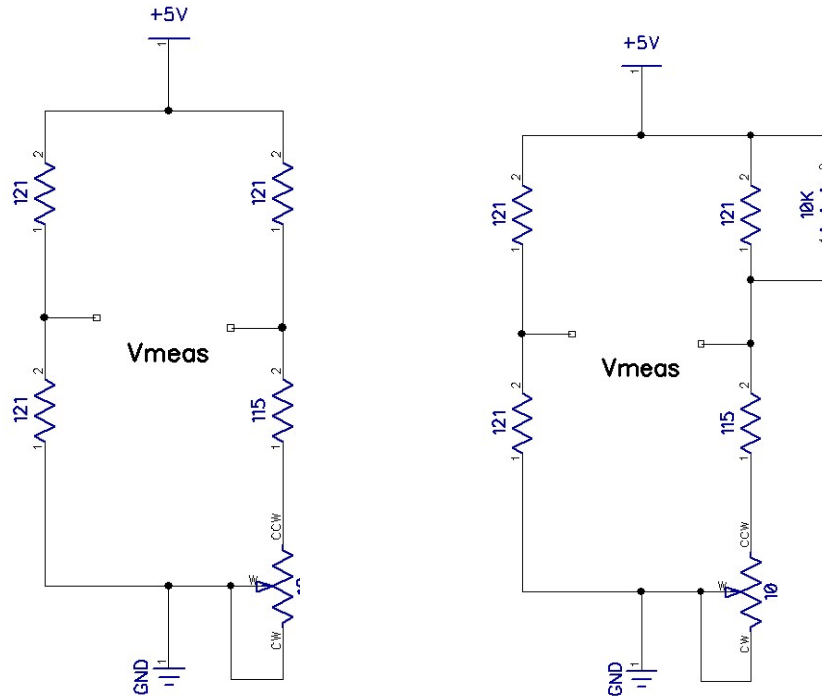


Figure 2: Simple bridge circuit, using resistors just to get started. Build the circuit on the left first, then watch the change as you build the circuit on the right.

You should notice that when you use the 100K resistor it gets harder to see the change in voltage. In order to sense smaller changes in resistance, we need to use an instrumentation amplifier. Build the circuit shown in Figure 3. 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. Rebalance the bridge to zero (or close as you can get) without the 100K resistor in the circuit.

Once the bridge is balanced, add the 100K resistor in parallel to the 121 Ω resistor which is the stand-in for your strain gauge; see Figure 2. Measure and write down the change in voltage when the 100K resistor is in the circuit or not.

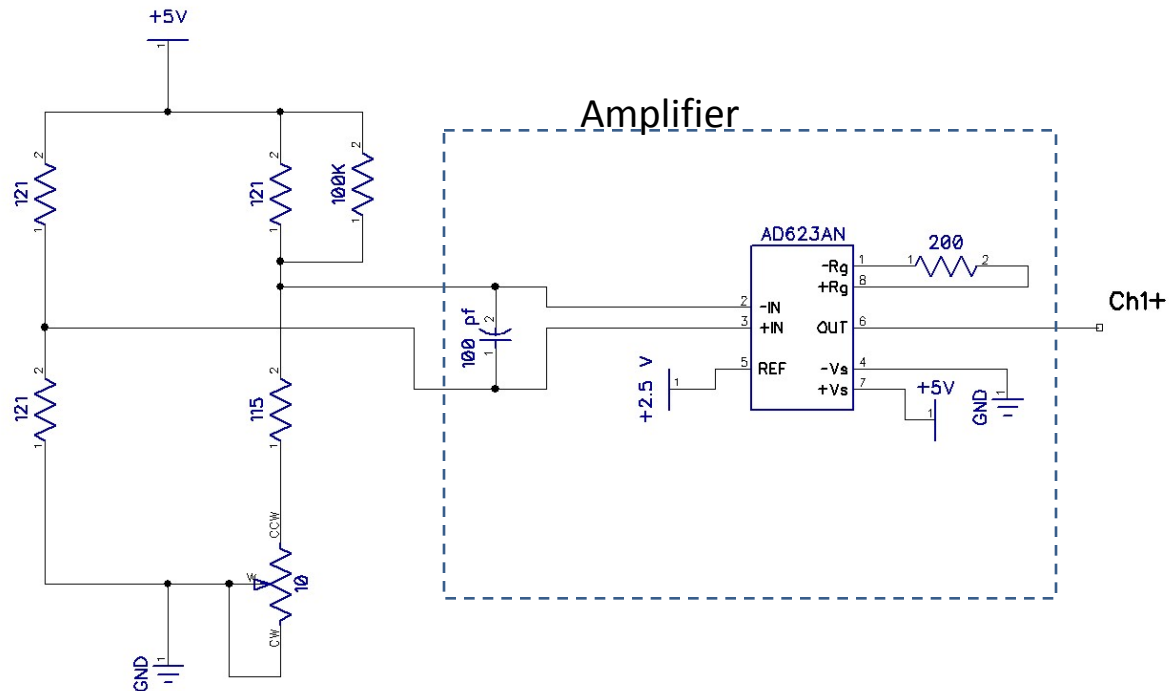


Figure 3: The 121 Ω resistor in the upper right branch of the bridge is the stand-in for the strain gauge. The change in the measured output as the 100K resistor is added is a stand in for the change in resistance in the strain gauge circuit. The negative input for Channel 1 should be connected to 2.5 V

Repeat the experiment with a 499K and 1M resistor instead of the 100K. Derive an expression for the change in the voltage that you measure at the output to the change in the resistance of the upper right branch of the bridge circuit (see notes from Monday class). Compare this result with what you measured at 100K, 499K and 1M. You should get very good agreement.

Now replace the 121 Ω 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. See Figure 4 for the final strain gauge measurement circuit.

Get one of the beams with the strain gauge already mounted on them. Check the quality of the connections – both electrical and mechanical. If yours is defective give it to one of the instructors to put in the bin to fix. Cantilever the beam using a bar clamp to the edge of your desk. The strain gauge should be just hanging over the edge of the desk. Re-balance the bridge by adjusting the potentiometer. Once it is balanced, try pushing down 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.

When you are finished KEEP YOUR WORKING CIRCUIT INTACT. We will use it next week. Just remove the strain gauge beam and leave it in the lab.

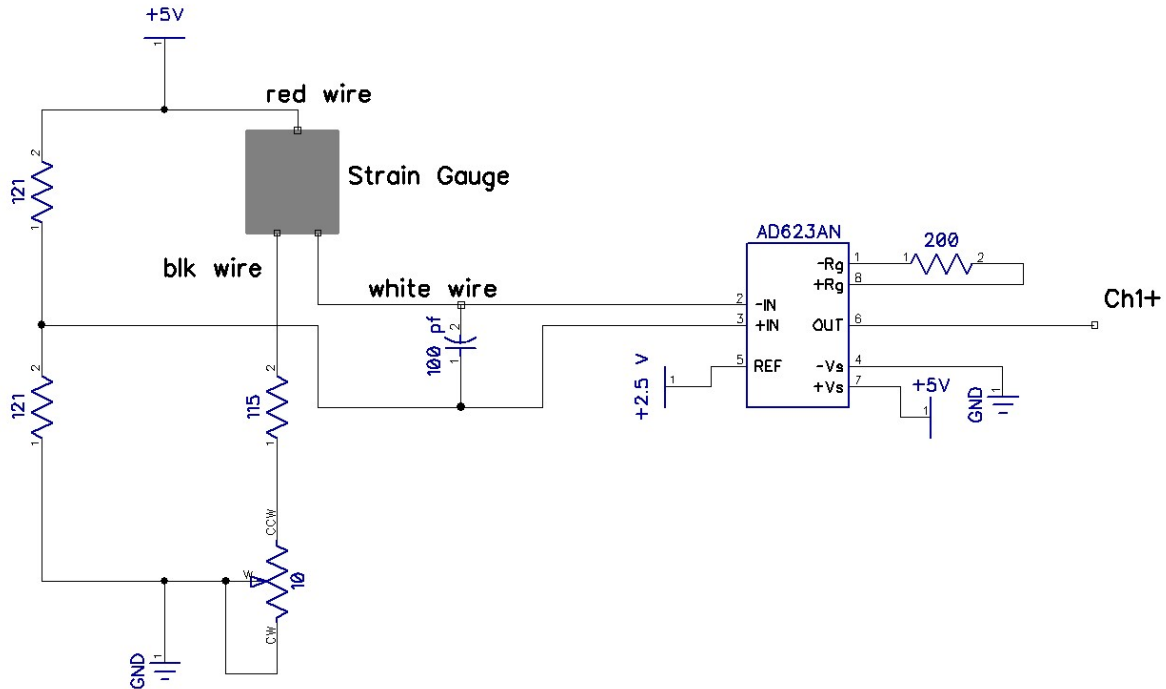


Figure 4: Final strain gauge circuit.

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 instrumentation amplifier output to the change in resistance on the Wheatstone bridge. Compare this analysis to the measurement with the 100K, 499 K, and 1M resistor.
- 2) A single plot of circuit output as a function of time as you add one weight instantaneously. Can you use your circuit analysis to figure out the change in resistance at the strain gauge for the weight applied?
- 3) Take a picture of your awesome looking circuit.