

## Lab 2: Resistance measurements and the polygraph

### Resistance measurements - individual

This week we will be exploring resistance measurements and in the end you will build a polygraph to find out if you are lying about how much you are studying for this course. We will start with some simple measurements and incrementally building a circuit with known resistors just to make sure that we know what we are doing. This idea of measuring small changes in resistance will come in handy later when we build some experiments using strain gages.

Start with the simple circuit shown below in Figure 1. Note that M means megaohm. Measure the voltage at the center point with respect to ground using the DAQ. Write a short program that takes 1 second of data at a sample rate of 1000 Samples/sec. You probably can accept the defaults for the analoginput object. You will want a differential measurement with one channel of data. Take the mean voltage over a short time and compare to the analytical solution of 2.5 V. You will find that the answer is way off due to the resistor network (input impedance) of the DAQ. Comment in your lab report on your measured value versus the expected value which considers the resistor network inside the DAQ.

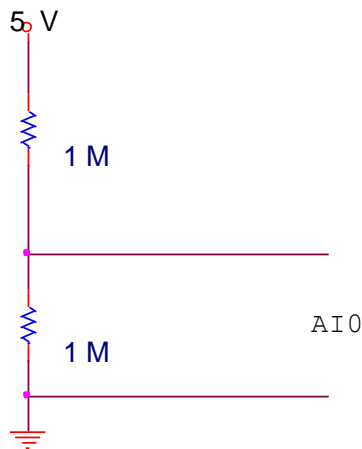


Figure 1: Simple voltage divider

To solve the input impedance problem, add an op-amp follower as shown in Figure 2. Now you should read approximately 2.5 volts on AI0. However, note that the 5V supply is not exactly 5 V. This power supply comes from the USB and may not have a very tight tolerance. Add a measurement of the 5V power supply to AI1. Compare the voltage that you measure at the op-amp output from the above circuit to the measured supply voltage divided by 2. See whether the voltage that you measure is closer to the predicted value if you use the actual supply voltage as opposed to the assumed 5V. Comment on this in your lab report, no need for a plot.

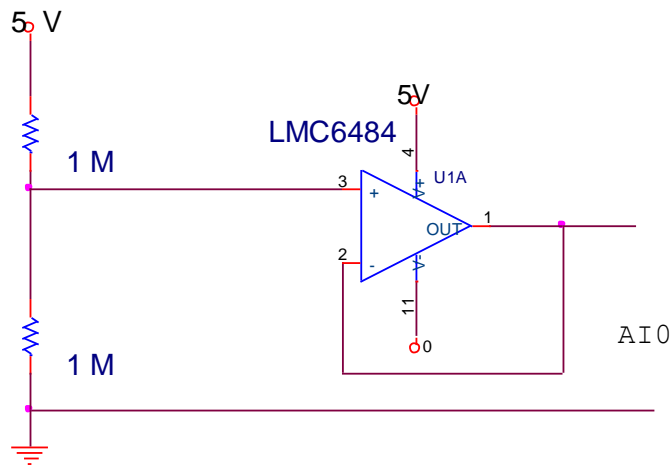


Figure 2: Buffering the voltage divider with an op-amp follower.

Now we want to be able to sense a change in resistance. So consider the circuit in Figure 3. Start with the variable resistor to be a 10K potentiometer. You will try to sense a 10 K change in resistance relative to 1 M, or about a 1% change. To improve your measurement resolution, measure the output of the op-amp (which should be approximately 2.5 V) relative to the 2.5 V voltage reference which comes from the DAQ (one of the voltage rails on the protoboard through our connector). Change your program such that the input range of channel 1 is between -1 and +1 V (instead of 10 V as the default) in MATLAB. As you run the program, twist the potentiometer to see that the voltage measured across AI0 is changing. Continue to measure the supply voltage with AI1 (not shown in the schematic for simplicity).

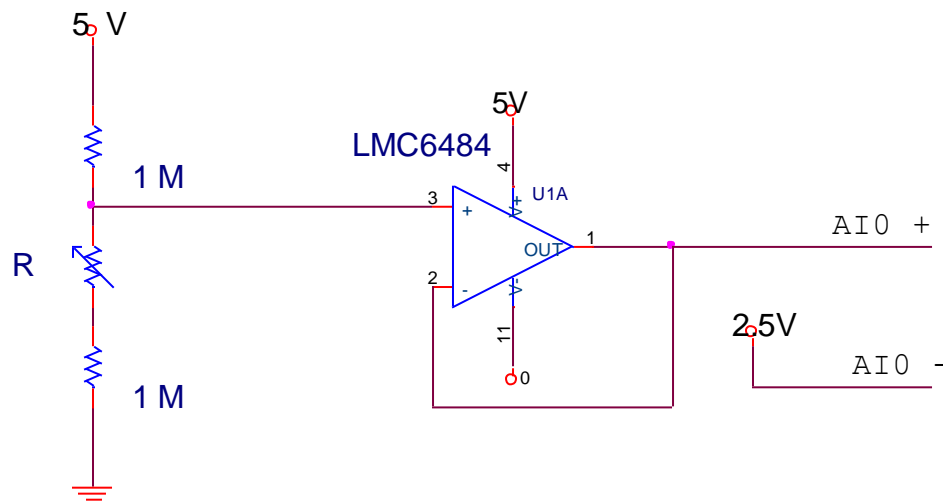


Figure 3: Measuring a small change in resistance.

In your MATLAB program, convert the voltage that you measure to that of the resistance of the potentiometer. You should notice that due to small errors in the system, the resistance that you

measure is probably not correct in absolute terms, however it should be good in relative terms. By this we mean that as you change the potentiometer from one extreme to the other, you should see that the resistance changes by about 10K, though not exactly as the potentiometer resistance value of 10K has 10% tolerances. In determining the measured resistance, use your measured value of the supply voltage, not the nominal 5 V. Show a graph of the potentiometer resistance change in your report. Include the equation for how you convert from measured voltage to resistance of the potentiometer.

You probably noticed that there is a fair amount of noise in your system. Much of this is unavoidable. If you look at the raw data from AI0, you will probably see a fluctuation on the order of a few mV, which leads to the wild changes in resistance. Show a graph and comment on the noise level in the raw signal. Using your equation, determine how many ohms/mV. By this we mean, if the raw measurement is determined to be off by 1 mV, how many ohms of error does this translate too? The simple way to find this number is to plug a measured voltage of say 2.5 V to your equation. Then plug in 2.51 volts and see what the change in resistance is. The more formal way to do this is to take your equation and take its derivative to find the slope.

Since the potentiometer is not that well controlled, let's test how accurate our system is in a simple way. To get a more exact measurement, replace the variable resistor in Figure 3 with a fixed 10K resistor. Run your program for a short time and take the mean of the resistance measurement. Now remove the 10K resistor and replace it with a wire (short). Repeat the measurement and take the **difference** in the mean resistance between the two experiments. You should get a number pretty close to 10K. Repeat the process for a 1K resistor and see if you can measure a 0.1% change in resistance. Provide the results of the 10K and 1K test in your report. Include your measured resistance change versus the actual change.

Now let's put the potentiometer back and try to filter our signal a little to make it more beautiful. We can use a simple RC low-pass filter (from last semester) to try to clean the data up. However, we have to be careful adding a RC filter as we might introduce the impedance mismatch problem that we had to solve in the first place. So build the circuit in Figure 4. Note that you should look at the data sheet for the quad LMC6484. Rather than following the pin numbers below for the +, - and output of the op-amp in the second op-amp, you can wire into another op-amp on the same quad chip. We will leave this to you to figure out.

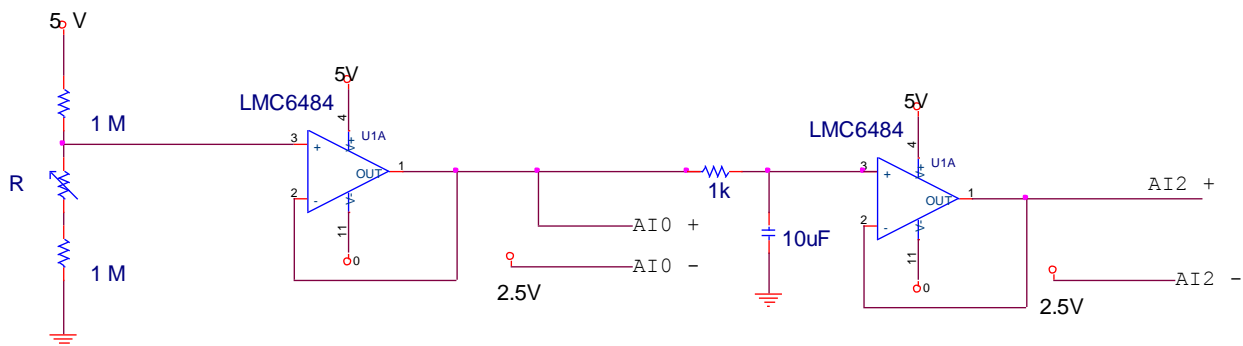


Figure 4: Adding a low-pass filter to our measurement.

Now repeat the experiment with the 10K potentiometer and compare (in your lab report) the difference between the filtered and unfiltered data. Note that the filter might introduce a bias up or down, though the relative change should still be as accurate as before.

At this point, the signal should look better but will be somewhat noisy. Try adding the following software filter to your data. You can include a chunk of code as follows, where the code assumes a vector named "R" which contains the sampled measurement of the resistance in a vector of R versus time.

```
Rf(1) = mean(R(1:100));  
a = 0.95;  
for i = 2:length(R)  
    Rf(i) = Rf(i-1)*a + (1-a)*R(i);  
end
```

Try different values of "a", though by its definition a must be less than 1. In your lab report show 1-2 graphs comparing the raw resistance measurement, the hardware filtered data, and the software filtered data.

## Lie detector - can be done with a lab partner.

In this experiment, we will demonstrate the use of a simple circuit to perform a crude type of biometric measurement known by many names: Galvanic Skin Response (GSR), Electrodermal Response (EDR), Skin Resistivity, Psychogalvanometer and others. We will be measuring the DC resistance between two points of electrical contact with the skin. This simple measurement has served as the basis of numerous gadgets and instruments, some useful and some whimsical, for nearly 100 years.

### About the measurement

Changes in skin resistance are known to be correlated with psychological stress. Skin conductivity (the inverse of resistance), is known to increase with the activity of the sweat glands, since sweat is a saline solution that is a reasonably good conductor of electricity, while dry or calloused skin is an insulator unless high currents cause cellular damage, as in electrocution. Therefore, the resistance, measured in ohms, tends to decrease with stress. This principle was first used legitimately in 1926 by Leonard Keeler as part of an



improved form of a lie detector<sup>1</sup>, and devices using this principle have been known as Keeler Polygraphs since then. Whether skin resistance is useful in discerning truth from fiction remains dubious, although this measurement remains one of the several used in a modern polygraph test. It has been used as an indicator of stress and for biofeedback, both legitimately and illegitimately, with applications ranging from measurements of human reactions to images by MIT Media Labs<sup>2</sup>, to the classic “Kiss-o-Meter”<sup>3</sup> arcade machines found at amusement parks from the 1930’s through the 1970’s. It is the measurement made by the “E-Meter” used by the Church of Scientology<sup>4</sup>, and has been known to be used by various religious cults. It is a popular science project in elementary through high school, and even Radio Shack division of Tandy Corp. sold a [Lie Detector Kit](#)<sup>5</sup> and Biofeedback Science Project kit, pictured here<sup>6</sup>.

Fabricate the circuit in Figure 5, and connect it to the AIO differential inputs of the DAQ to read the measurement into MATLAB. A template file that runs in continuous mode and plots is on the website if you want to use that to get started, or you could write your own.

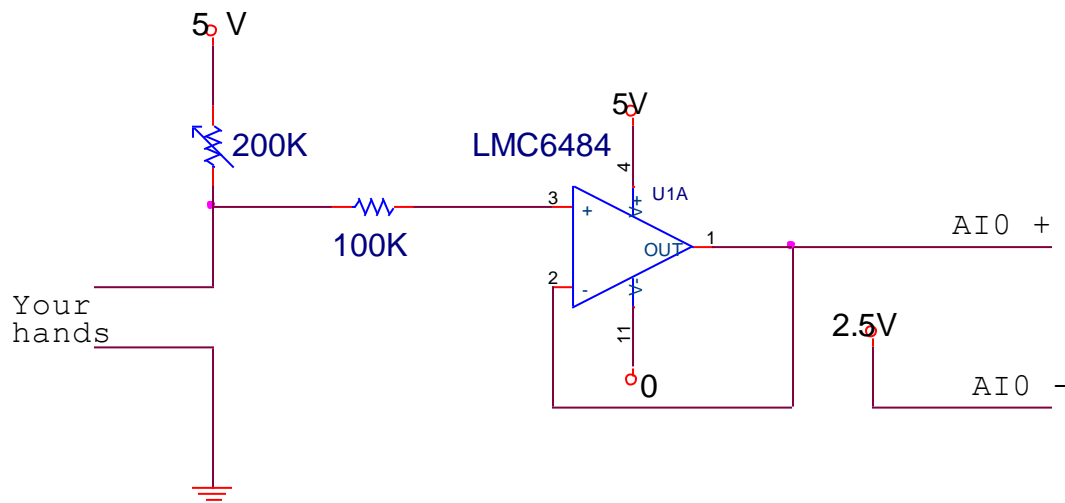


Figure 5: Lie detector.

The LMC6484 quad operational amplifier (Op Amp) is used as a unity-gain follower or high-impedance buffer, to prevent the DAQ inputs, which have a 150 Kohm impedance, from loading the high-impedance point of measurement – just as we used in the previous part of the lab. The Op Amp should be powered with the positive voltage supply pin connected to the 5 volt supply from the DAQ, and the negative voltage pin connected to ground. The 100K resistor at the op-amp circuit is not really needed,

<sup>1</sup> The Polygraph: The Modern Lie Detector, [http://www.umw.edu/hisa/resources/Student%20Projects/Singel/students.umw.edu/\\_ksing2os/polygraph/origin.html](http://www.umw.edu/hisa/resources/Student%20Projects/Singel/students.umw.edu/_ksing2os/polygraph/origin.html)

<sup>2</sup> MIT Media Laboratory <http://www.media.mit.edu/research/groups/affective-computing>

<sup>3</sup> “Kiss-O-Meter Fortune Teller by ESCO Exhibit Supply Co.” <http://www.arcade-history.com/?n=kiss-o-meter&page=detail&id=14240>

<sup>4</sup> “Secrets of Scientology: The E-Meter” <http://www.cs.cmu.edu/~dst/E-Meter/>

<sup>5</sup> From <http://www.samstoybox.com/toys/LieDetector/lie00.html>

<sup>6</sup> From <http://www.extremenxt.com/gsr.htm>

however there are specifications for safety reasons to protect people from possible shock when doing experiments with people. While exceedingly unlikely, it is theoretically possible, that multiple failure occur in the power for the building, your laptop, the DAQ (essentially all at the same time), and you get shocked through the foil. The specification requires at least a 100K resistor between you and the electronics.

The human subject (that's you) places their hands on the "Skin Contacts" which are just two 10" x 10" pieces of aluminum foil, as shown below:



Figure 6: Our scientific electrodes for the lie detector.

The "tester" should now run your program in continuous mode. The "tester" will need to adjust the 200K trimpot (variable resistor) manually until the voltage difference across A10 is approximately zero when the subject's hands have been on the foil plates for a while (30 seconds or so). The circuit will now sense the change in resistance as you sweat. The "tester" should interrogate the "subject" about their study habits for this course and report anyone who appears to be lying about how hard they are working.

In your lab report, show a few snapshots of the measurement. You may collect this data as a pair and share it.

Just for fun, we can combine sound with present experiment. If you have time and are interested, try to modify the program to emit a continuous set of tones with frequency proportional to your skin resistance. This may actually be considered a crude form of biofeedback, since the subject will learn quickly how to adapt their skin resistance to maintain a constant-pitch tone. This step is not required.