

Capacitors and Humidity Measurement

In this week's lab, we will start to use capacitors and learn about their wonders. There are four parts to this lab, all connected by the fundamental behavior of the capacitor. The parts may not seem inter-related the first time you work through this lab, however, they are.

Part 1: Build some intuition

Start with your experiment from last week with the strain gauge. Go back, look at last week's lab, and get everything working again (plug in your beam and connect channel 1 of the Scope to the output of the instrumentation amplifier). Now add a single RC circuit onto the end of the instrumentation amplifier (see Figure 1). Use a 10K resistor and 100 μ F capacitor as shown in Figure 1. Monitor the output of the RC circuit with channel 2. **Display Ch1 and Ch2 on the same y-axis voltage scale on your Scope screen. Set the time scale to 1 sec/div.**

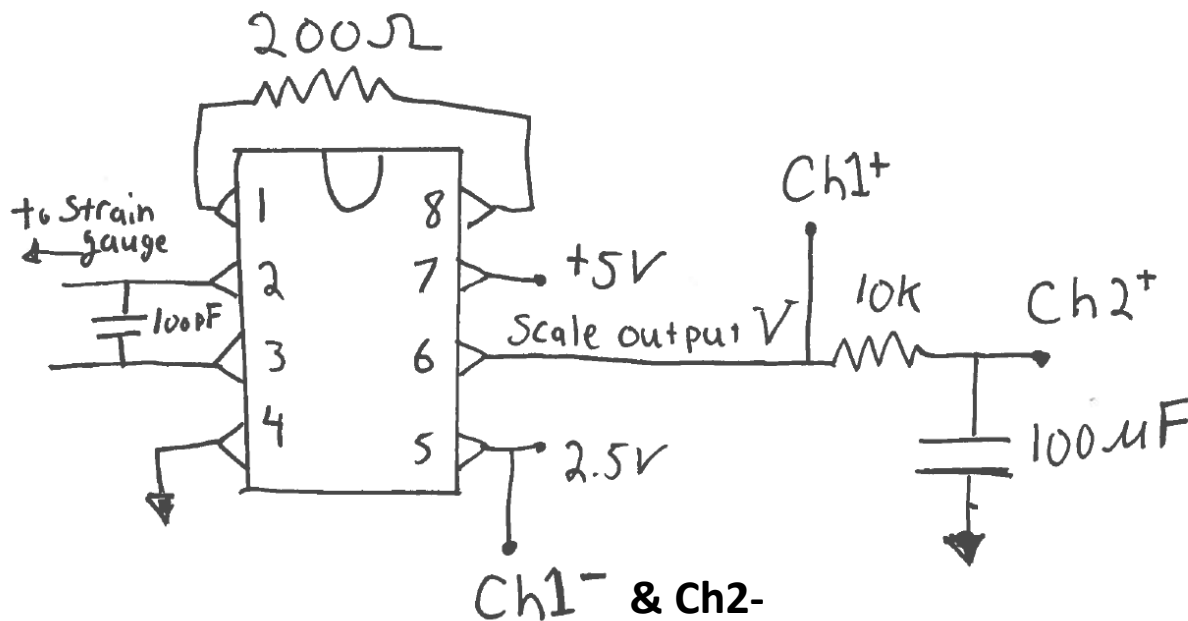


Figure 1: The left part of the circuit is from last week. You only need to add the right most resistor and capacitor off the scale's output voltage.

Push the beam (gently, no need to bend them in half) and watch how the output of the RC circuit (Ch2) changes with respect to the original signal from the scale (Ch1). Try to

1. Move the beam up and down slowly, like a low frequency sine wave.
2. Move the beam up and down rapidly, like a high frequency sine wave.
3. Move the beam suddenly and hold it (like a low frequency square wave).

There is no need to collect any data or report on this part of the experiment for your lab report. The only purpose is to build some intuition for how the output of a single RC circuit behaves. Just because you do not need to collect any data, do not rush this step. In fact, leave the circuit intact and try it again after you have done the rest of the lab. This step will allow you to see in real-time what the RC circuit does. It somehow seems useful to explore this application because you can change the signal going to the RC circuit by hand.

Part 2: Controlled RC circuits

Now that you have seen the behavior qualitatively, we will be quantitative about the RC circuit behavior.

On your bread-board, place a $1\text{k}\Omega$ resistor in series with a 0.1 micro-farad (μF) capacitor. Place the yellow W1 wire from the Analog Discovery on the resistor and **one of the black ground wires on the ground of your breadboard. You should have nothing connected to the 5 Volt power rail on your breadboard.** Finally measure the voltage across the whole circuit with input channel 1 (orange wires) and the voltage across the capacitor with input channel 2 (blue wires). The negative side of both input channels (the orange/white and blue/white wires) should be connected to ground.

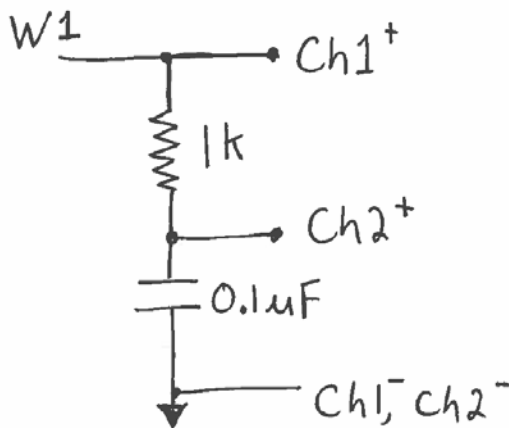


Figure 2: Simple RC circuit for part 2 of the lab.

Open the Waveforms software. Open “WaveGen” on the main screen. “WaveGen”, the Arbitrary Waveform Generator, will allow you to set an output waveforms type (square, sine, triangle), amplitude, and frequency. We used this feature in Lab 1 where we used the DC (or constant) output. Set the waveform type to a square wave. Set the frequency to 500 Hz. Set the amplitude to 500 mV. Set the offset to 500 mV. This will create a 0 to 1 volt square wave with a frequency of 500 Hz. Hit the “Run” button such that the Analog Discovery will begin to output this signal on the W1 (yellow) wire.

Now open the Scope. On the right, turn both channel 1 and channel 2 on. Set the time scale to $500\ \mu\text{s}$ per division, the voltage scale to 500 mV/division, and the voltage offsets to zero. If the signal is scrolling

by on the screen, you may need to adjust the Scope's trigger (we can explain this in class). Once you have everything set, export the data (both Ch1 and Ch2). Exporting will allow you to later import and plot the data in MATLAB (or Python) as described in Lab 1. **You will need a plot of this data for your lab report, so be sure you have it saved before you move on.**

While the Scope is running, go back to the WaveGen. Turn the frequency up to 1.5 kHz and see what happens. **Capture this data in the same way as the 500 Hz data.** Now, try adjusting the frequency up and down to observe what happens to the output signal as frequency increases. The behavior you observe should be the similar as in Figure 3.8 of the [book](#) (page 38 of the book or 42 of the PDF).

Turn on a measurement of channel 2's amplitude. Select "view", "measure", "Add", "defined measurement", select "Channel 2", "vertical", "amplitude". Now adjust the frequency successively to: 500 Hz, 1 kHz, 2 kHz, 5 kHz, 10 kHz, 20 kHz, 50 kHz, 100 kHz, and 200 kHz. Record (on a piece of paper) the frequency and amplitude of channel 2 at these 9 frequencies. **For your lab report you will plot this data on a log-log plot.** To create a log scale plot in MATLAB you can type,

- `loglog([500 1e3 2e3 5e3 1e4 2e4 5e4 1e5 2e5],[x x x x x x x x x])`

where "x" are your recorded values of amplitude. You will need this plot (with appropriate labels) in your lab report.

Part 3 – Capacitance measurement

Now, take the same circuit as part 2 and switch the R and the C, as shown in figure 3. Run the square wave on the "WaveGen" at 500 Hz as before. Capture Ch1 and Ch2 as a function of time and export the data as before. **You will need a plot of this data for your lab report, so be sure you have it saved before you move on.** Before moving on, convince yourself that Part 2 and Part 3 are really the same circuit. Convince yourself that the output you now see is the same as if in Part 2, if you took Ch1 and subtracted Ch2 (i.e. took the voltage difference across the resistor). Again, you don't need to include this observation in your lab report, we are just pointing out some interesting things to think about as you move along.

Now turn of the measurement of amplitude from Part 2 and turn on a measurement of root mean square (AC RMS) amplitude. [Look up the difference](#) between the different types of amplitude. If you are confused by the definition, ask one of the instructors. Note that the RMS is a measure of the average value of the voltage and not the peak. Once you have the measurement, replace the 0.1 capacitor with a 0.047 μF capacitor. Note that the signal decays faster and the RMS value has decreased significantly. This observation should convince you that you could use this principle to build a capacitance meter.

Ultimately, we will use this idea to build a humidity detector (last section). The humidity sensor we will use in the next section has values between 160 to 190 pF. Therefore, let's create a calibration curve which relates the measured RMS amplitude to the known capacitance. Build the CR circuit like in Figure 3, **but using 10K a resistor** and the following values of C in the table. Since the decay is more rapid

with these small capacitance values, **change the driving frequency of the square wave in WaveForms to 10 kHz**. Fill in the table below and generate the plot for your lab report.

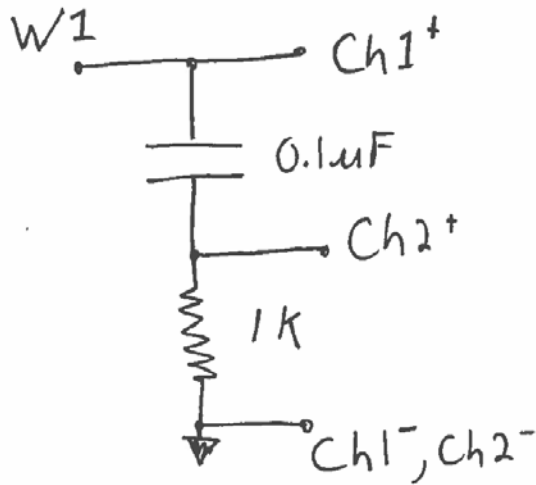


Figure 3: Circuit for Part 3 of the lab. Note that when filling the table you will change the values of both R and C.

| Capacitance value (R=10K) | Measured RMS amplitude |
|---------------------------|------------------------|
| 100 pF | |
| 120 pF | |
| 150 pF | |
| 180 pF | |
| 220 pF | |

Part 4 – Humidity measurement

The principle of a low cost humidity sensor is one whose capacitance changes due to the humidity of the environment. Measure capacitance and you can measure humidity.

Replace the capacitor in your circuit with the [humidity sensor](#). **Take the measurement of the RMS amplitude**. From the RMS amplitude, your calibration data from Part 3, and the data sheet for the [humidity sensor](#), figure out the relative humidity of the room. Check your value to the relative humidity of the day (which you can check at [weather.com](#))

Deliverables:

The results you need to save are highlighted in **RED** in the lab above, just to help remind you as you go along what to save. The summary is listed below.

- Part 2 RC: Plot the result of the 1 volt square wave at 500 Hz into the RC circuit. Compare the measured time response (voltage versus time) of the decay from 1 to 0 volts (you can just use

the first millisecond of measured data) to the predicted response we discussed in class. $V = e^{-t/RC}$.

- Part 2 RC: Plot of voltage versus time when the input frequency is 1500 Hz. Compute the characteristic frequency of the circuit ($1/RC$). This frequency is in radian/sec and should be divided by 2π to get Hz (cycles/sec). Comment on the relationship between the computed “characteristic frequency” and the response seen at 1500 Hz.
- Part 2 RC: log-log plot of amplitude of the output as a function of frequency. Provide some comment on what this result is telling you.
- Part 3 CR: Plot the result of the 1 volt square wave at 500 Hz into the CR circuit. Comment on the difference with the RC circuit.
- Part 3 CR: Plot your calibration data for the capacitance meter that you created (i.e a plot of the table data).
- Part 4 Humidity: Report on your results of using the capacitance meter you built in Part 3 to measure the relative humidity.