Experiment #02
RC Transients

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1 Objective

In this experiment you will measure the transient response of an RC circuit after a sudden change in the applied voltage. The data you collect will take the form of an exponential decay, which you will then fit to determine the time constant of the circuit. Repeating this for different values of resistance will let you further examine the relationship between time constant and resistance. This work is intended mainly to give you more practice with the electronics, and more opportunities to fit different models to data.

In Experiment #04, you will revisit this circuit and its use as a filter, the application that it will be used for in your radio-building at the end of the term. **Please keep the resistor and capacitor that you use today in the box with your circuit board.** Experiment #04 depends on using the same components as this experiment.

1.1 Learning Goals

After finishing the lab you will:

- know the theory behind RC circuits
- know how to measure capacitance with a DMM
- take the next step in building multi-component circuits
- know how to trigger an oscilloscope to capture transients
- know how to fit data with an exponential in Python

2 Introduction to the RC Circuit

Consider the RC circuit shown in Fig. 1.

Suppose the power supply has been held constant at some constant value V_{in} for a long time prior to t=0. What is $V_c(0)$? Now suppose the power supply voltage is suddenly turned off at $t = 0$. You

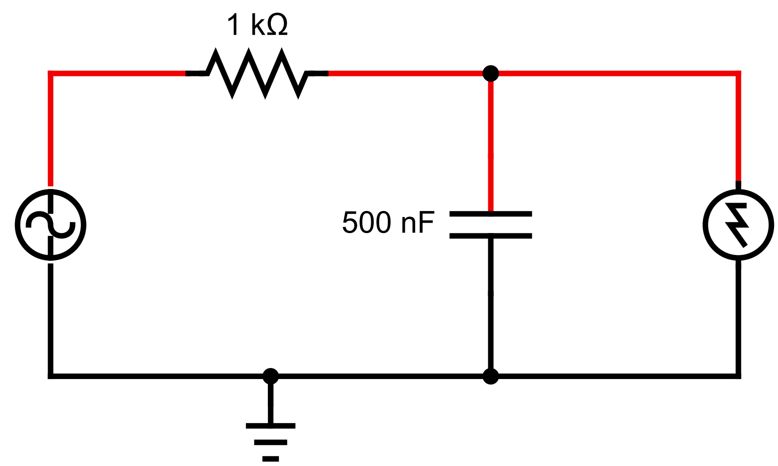

Figure 1: Circuit diagram for the series RC circuit with the scope connected to measure the voltage signal across the capacitor. The function generator can drive this circuit either in an AC mode with a sine-wave input, or in an "on/off" mode using a square wave.

can analyze the circuit in terms of Kirchoff's laws:

$$V_C - IR_1 = 0 \tag{1}$$

Recognizing that $I = -\frac{dq}{dt}$ we obtain the differential equation describing the charge on the capacitor:

$$\frac{q}{C_1} + \frac{dq}{dt}R_1 = 0 \tag{2}$$

Solving this gives an exponential, and substituting $q = CV$ predicts the capacitor will discharge through the resistor such that the voltage across the capacitor decays exponentially in time according to:

$$V_c(t) = V_0 e^{[-t/\tau]} - V_{final} \tag{3}$$

with $\tau = RC$ is called the RC time constant. This characteristic decay time is therefore set by the resistance and capacitance of your circuit, and determines the time it takes for the initial voltage to decrease to $1/e$ of the initial voltage, V_0.

From the values given in Fig. 1 estimate what the time constant τ is for this circuit.

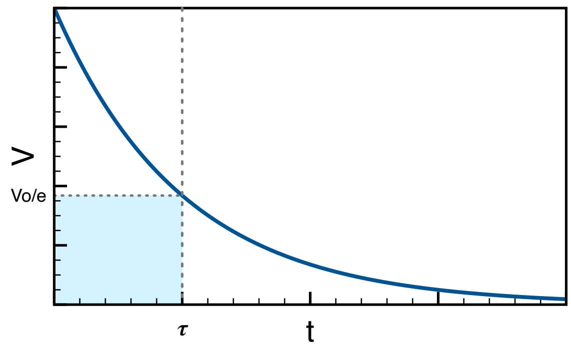

Figure 2: Example decay curve showing the characteristic decay time, τ.

Checkpoint 1

Calculate τ in your Jupyter notebook

3 A Brief Note About Lab Notebooks

Last week's Jupyter notebook had a fair amount of structure to help guide you and ensure everything was recorded. Going forward we will expect you to keep and structure your own notes. We will provide some structure this week, but you will see less and less as you become more comfortable with the Jupyter notebooks and the lab environment in general. Note that you and your partner should each record your own notes even though you are working together.

The most important aspect of your lab notes is that they are an accurate, complete, and unaltered record of your work in the lab, taken as the work is happening. You may feel most comfortable doing this by hand while setting up and starting measurements, or you may prefer to take notes digitally, directly in your Jupyter notebook. If you decide to take notes by hand, these still must form a robust and traceable record: take notes in a bound lab notebook (not scrap paper, looseleaf or from a spiral bound notebook), use photos of your notes to include them in your Jupyter notebook, and retain your written notes for your own records. The reason for this is two-fold: the photo is an accurate, unaltered representation, and this saves you time instead of copying over information redundantly. It is not expected to be perfectly neat, merely legible, and errors or revisions should merely be crossed out (not erased or altered with "white-out"). If you are taking all notes digitally you will find that you will need some way of creating diagrams/sketches and importing them: there are numerous drawing programs (e.g. Inkscape) and some online circuit drawing tools (e.g. www.circuit-diagram.org) that can help you create diagrams easily and quickly. While Jupyter notebooks do not lock and time-stamp entries (like many professional electronic lab notebooks, or ELN's do), we expect that you will maintain the spirit of a formal, unaltered record by **not deleting entries** and merely noting discarded sections.

However you create your notes: **all sketches, instrument settings, observations, reasoning for choice of settings, plots of data, and your analysis should be entered into your Jupyter notebook during the lab, not after**. We will offer some guidance in the Jupyter notebook for the lab (Experiment-02.ipnyb) which also contains python code for fitting an exponential decay model. We will be checking your work through the lab, both to help you, and to reinforce the habits of taking good lab notes.

4 Setting Up for Measurements of the RC circuit

The diagram for the series RC circuit you will build is shown in Fig. 1. Start by selecting a 500 nF capacitor and measuring its capacitance using the DMM. This is like the measurement of resistance that you did last week; you just select for measuring capacitance rather than resistance. You should also check the value of the 1 kOhm resistor that you will start with. Record your values in your notes. You can also now refine your estimate of τ with *your* measured component values, not just the nominal values.

Now build this RC circuit on the protoboard as shown in Fig. 3:

- Place your selected capacitor and the 1 kOhm resistor, so that they share the same column in the middle and thus are electrically connected.
- As with the last lab, it is convenient to have the generator output connected to a BNC Tee connection, so that you can send the generator signal to a channel of the oscilloscope, and also to your circuit.
- As before, you also connect to the circuit using the BNC-alligator-clip adapter. Use jumper wires to apply the voltage across the resistor-capacitor series combination. Consider where to place the ground so that you can measure a voltage across the capacitor relative to that same ground.
- The last step is to connect the other channel of the oscilloscope to the circuit so you can measure the voltage across the capacitor $V_c(t)$. Make sure the ground pin for the oscilloscope is connected at the same point as the ground pin for the generator.

You are now ready to measure the RC time constant by looking at the voltage across the capacitor in response to a sudden change in the applied (input) voltage. This is accomplished by applying a square wave with an amplitude of roughly 1V. The period of the square wave must be chosen so that it is several RC time constants; your aim is to capture the voltage decay from its start, until it has fallen down to it's final value, before the square wave jumps up again. Explain the reasoning behind your choice and record it in your notebook.

Tip 1

Displaying the input voltage (function generator) along with V_c can help you determine if you have chosen appropriate parameters.

Here are the main steps to make a measurement of the RC time

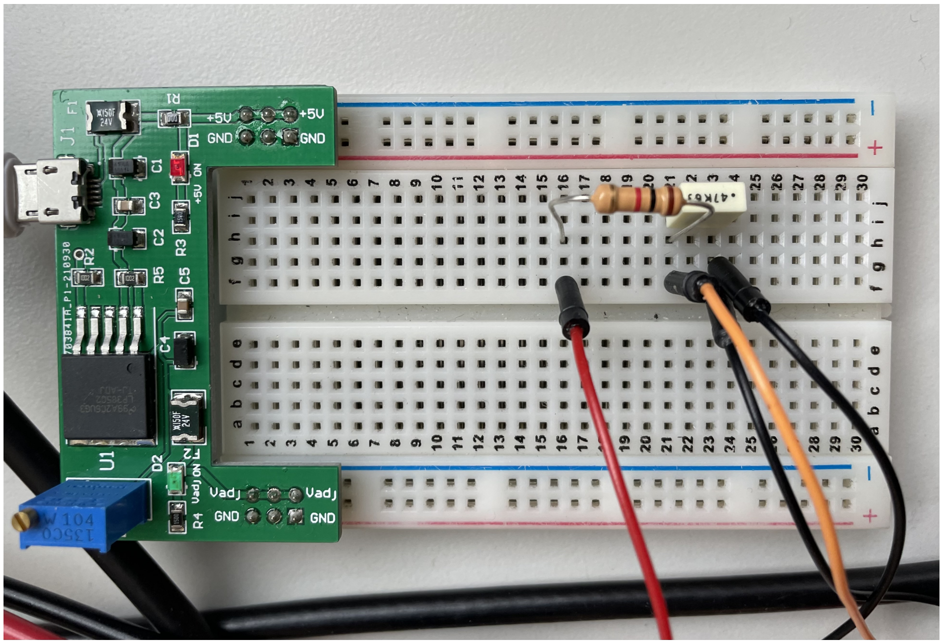

Figure 3: Example component layout on the protoboard for the RC circuit. Black jumpers are connected to ground, red is connected to the centre pin of the function generator output, and orange to the centre pin of the BNC connected to the oscilloscope.

constant in the time domain.

- set the function generator to square waves
- set an amplitude of roughly 1 Volt
- choose an appropriate period (consider the estimate of τ you made at the start of the lab)
- be sure to use DC coupling for the input channels on the oscilloscope
- Use your square wave (input voltage) channel for the triggering
- trigger on a falling slope using Edge triggering (you might want to make a choice based on what part of the cycle you want to see!)

An example of the what you should see on CH1 and CH2 of the scope is shown in Fig. 4.

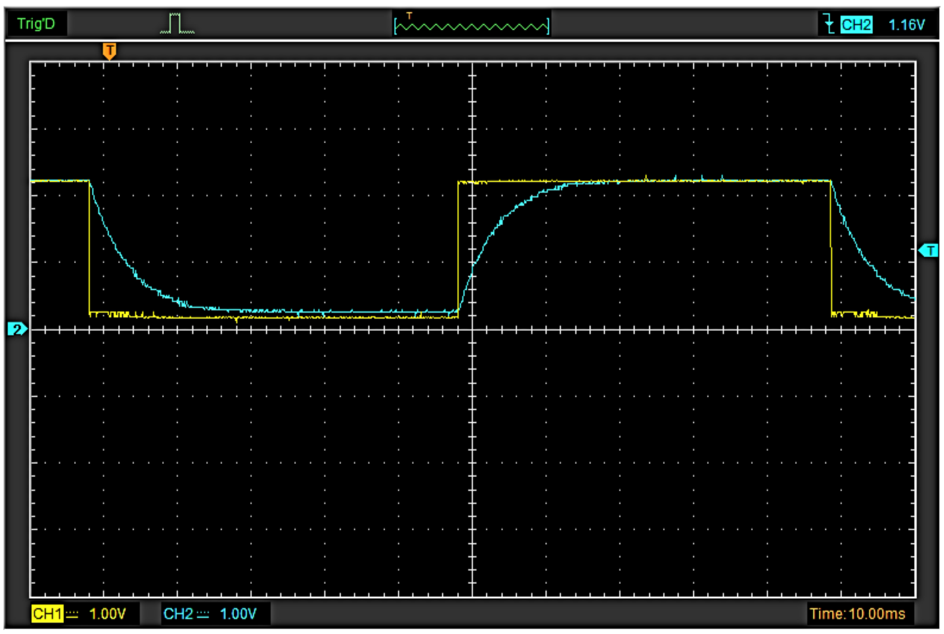

Figure 4: Example of input voltage on CH1 (yellow) and output voltage on CH2(blue) when measuring the RC time constant in response to a sudden change in applied voltage CH1. Note the exponential decay of the voltage on the capacitor (CH2) when the input voltage is turned off and also the exponential rise when the applied voltage is turned on.

4.1 Making and Saving Your Measurements

Describe the observed behaviour of $V_c(t)$. Remember to keep taking notes on your observations and measurements. Adjust the time scale, the vertical scale of the oscilloscope, and the trigger so you see a complete decay curve, using as much of the oscilloscope screen as possible.

Make a rough measure of τ using cursors to determine the time it takes for $V_c(t) - V_{final}$ to drop to V_0/e. Check that your estimate roughly agrees with your expectation.

Checkpoint 2

Call a TA and show them the signals on the scope as well as your circuit, and describe how you found τ from the oscilloscope trace.

Next, you should save the decay curve to a .csv file (you may want to save both signals for reference). As before, you save with these steps:

- Insert a USB drive into the oscilloscope output
- Enter the Trigger menu and select Save
- select the channel that you want to save
- Select CSV as the type of output
- Enter a filename and save the data
- Don't forget to record the filename in your lab notes so that you can keep track for your analysis

You will need to upload your data to your Jupyter account and then will be able to run codes like last week to plot the data, examine the noise, and pack your data with some averaging to reduce the noise.

This week's code includes the ability to fit an exponential decay to the data. This is just a minor change from last week's code, by simply changing the fitting function being used. Almost everything else stays the same, although we have made the steps more compact.

Once you have successfully fit the data, compare the value of τ from the fit to your initial calculation from your measured component values.

Checkpoint 3

Load at least one of your oscilloscope traces into your Jupyter notebook and complete an exponential fit. Call a TA over to review the output.

To complete your data acquisition, you need to collect decay curves for other resistance values. Try a fairly wide range of resistance values so that we can test the theoretical relationship between time constant and resistance. You will be using this data in the Week 5 analysis assignment, so make sure you collect enough data to use for fitting (absolute minimum 4 resistance values, more is better so if you have time keep going).

Each decay curve should be stored to a different data file, so try to use filenames that make sense (e.g. include the resistance value in the filename) and remember to record the names in your lab notes so that you don't lose track.

The remaining guidance for data analysis is embedded in your Jupyter notebook. You will need to fit all of the decay curves that you collect, but once you have done this once, it is very quick and simple to run the code on a new data file.

Before you leave the lab!

Make sure you:

- Put the resistor and capacitor that you used today in the box with your circuit board and keep it separated to use in the next labs.
- Have had your oscilloscope signal checked (Checkpoint 2).
- Have loaded at least one data set into your jupyter notebook, completed the fit and had it checked by a TA (Checkpoint 3)
- Have collected and saved .csv files for decay curves for **at minimum 4 resistance values**
- **Complete a final labnote check with a TA and upload your notebook before leaving the lab** (as last week, you can continue to work on fitting your data and commenting on the results and re-upload until the deadline, however this serves as a check that your export is working and a record of your notes up to this point).

