# Experiment #1
# Frequency Domain Response of an RC Circuit
# ENPH 259

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## 1 Objective

In this experiment you will study the steady state frequency response of an RC circuit and use your results to determine the measure the value of the capacitor. Specifically you will:

- measure the capacitor of an RC circuit by determining the time constant of the RC decay time;
- measure the capacitor of an RC circuit by measuring the amplitude response as a function of frequency;
- compare all measurements (with uncertainties) and discuss any disagreements.
- understand functionality an RC circuit and how it is used in electronic circuits

## 2 Prelab

Complete these two tasks and place them in your labnotebook **BEFORE** your lab begins and turn in a PDF on Connect. TAs will also be checking that you complete the pre-lab.

- With regard to Fig. 1, sketch the expected waveforms of $V_{in}$ and $V_C$ when the input is a square wave. Given the time constant of the circuit, what is the frequency of the square wave you should use for $V_{in}$?
- Using MATLAB, plot the frequency domain response of an RC circuit given in eqn. 4 for the circuit shown in Fig. 2. What does the RC circuit do to the frequency content of the input voltage signal?

# 3 Introduction

Consider the simple RC circuit shown in Fig. 1 with the scope disconnected.

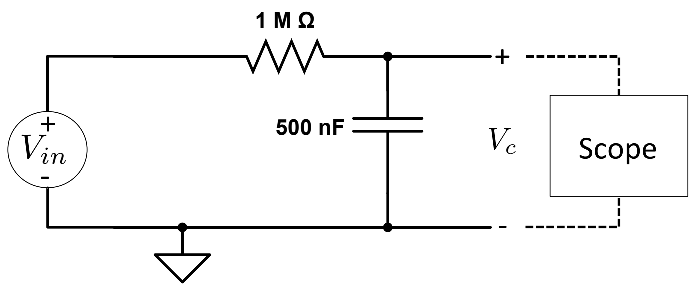


Figure 1: Simple RC circuit

If $V_{in}$ is a DC voltage source that is instantaneously turned off, then for $t > 0$ the capacitor will then discharge through the resistor and the voltage across the capacitor will be a function of time following this relation,

$$V_c(t) = V_c(t)|_{t=0}\, e^{-t/\tau} \tag{1}$$

with $\tau = RC$ being the time constant. From the values given in Fig. 1 estimate what the time constant is for this circuit. If $V_{in}(t < 0) = 10$ V, what is $V_c(t = 0)$?

# 4 Experiment

## 4.1 Time Constant Measurement Using Scope/Function Generator

First set up the circuit shown in Fig. 1 with the scope connected and use a function generator to provide $V_{in}$ (and thus not a DC voltage supply). On the oscilloscope, measure $V_C$ on channel 1 and the output voltage of the function generator, $V_{in}$, on channel 2. A BNC T can be used to split the signal of the function generator. Set the function generator to square wave output (with zero offset) at a low frequency since the time constant of this circuit is quite long. As you want to measure the time constant of the RC circuit, *carefully think about what period (i.e. frequency) of a square wave you should use.* What do you expect $V_C$ to look like? And what is the relevant time scale? Next download what you observe on channels 1 and 2, plot the data in Matlab (with labelled axes) and place in your lab notebook and describe what is occurring.

A quick estimate of the time constant can be made by measuring the time it takes for the voltage across the capacitor to drop to $1/e$ of its initial value at a falling edge of the square wave (the voltage that is reached after a long time can be treated as zero for this measurement). Use the cursor functions for this measurement and attempt to minimize your uncertainties by properly adjusting the horizontal and vertical scales. If you are confused on how to accomplish this, ask a TA or the Instructor. Next, compare the measured time constant with that expected from the component values (remember, meaningful comparisons require error estimates) and explain any discrepancies. You will likely have a factor of two difference between the two and you must explain the origin of this discrepancy. Finally, in preparation for the last section of the lab, measure the 1 MΩ resistor with the DMM and thus determine (with proper uncertainty) a value for $C$.

## 4.2 Frequency Response of an RC circuit

In the previous section, you measured the transient time domain response due to a sudden change in the (constant) driving voltage of the RC circuit. As you will learn in your ECE classes next year this response contains enough information to fully characterise the circuit. However, it is often much more physically intuitive and sometimes more useful to examine the response of circuits (and nearly everything such as structures, airplane wings, etc.) directly in the frequency domain.

First, construct an RC circuit similar to the very first one you examined in section 4.1 except change the resistor to 1k Ohms as shown in Fig.2. In this

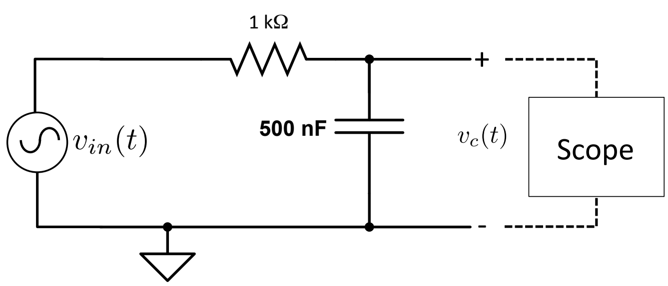


Figure 2: Simple RC circuit to measure steady state response

case the input voltage will be a sinusoid input from your function generator

$$v_{in}(t) = V_{in}\cos(\omega t) \tag{2}$$

where $V_{in}$ is a constant amplitude of the sinusoid. As in section 4.1 use the scope to measure $v_c(t)$ which should also be in the form of a sinusoid with perhaps a different phase and amplitude but the same frequency $\omega$,

$$v_c(t) = V_c(\omega)\cos[\omega t + \phi(\omega)] \tag{3}$$

The amplitude $V_c(\omega)$ and phase delay $\phi(\omega)$ are explicitly written as function of frequency ($\omega$) because as you will see they both depend on it. Vary the frequency over the range of 5 Hz to 10 kHz and record values of $V_c(\omega)$ by using the cursors for these measurements. Space your data points such that you are able to resolve changes in amplitude while maintaining efficiency. For example, if from 50 Hz 200 Hz the voltage doesn't change much (less than $\approx 2$ %) then only take a few points between these two frequencies. Ideally, you should quickly take a rough set of data, identify where the signal is changing rapidly and take more data points around those changes. Next, plot the data with MATLAB on a log-log plot and take any additional points necessary to interpret your data.

From the following expression derived in tutorial,

$$\frac{V_c(\omega)}{V_{in}} = \frac{1}{\sqrt{1 + (\omega RC)^2}} \tag{4}$$

and plot the RHS as a function of $\omega$ in MATLAB as well using your measurement for R and your expected value for C. Compare the two plots and adjust (by hand) the value of C to best match your experimental data. Does the best value of C fall within the uncertainty range for the expected value of C?

# 5 Applications of RC circuit

Looking at the amplitude plot, what function does this resistor/capacitor combination provide in terms of frequency? How does it modify the frequency content of the input? Try inputing a square wave and vary its frequency....what is the result on the capacitor's voltage?

How could you use an RC circuit in your stereo?

# 6 Conclusion

In your lab writeup make sure you answer all questions and include all circuit designs with explanations as well as MATLAB code you used to plot your data and model. In addition you should compare your three values for C –spec'ed value, rough measurement in time domain, and measurement in frequency domain– along with an uncertainty for each measurement to determine if all four measurements agree within uncertainties.