Experiment A5
Electronics II
Procedure

Deliverables: Check lab notebook, graded plots

Overview

In the previous two labs, you looked at simple DC (direct current) circuits, where the voltages and currents remained constant in time. In this lab, you will examine AC (alternating current) circuits, where current and voltage oscillates sinusoidally with time. In particular, you will build an electronic filter that blocks low frequency signals and passes high frequency signals. Such a circuit might be used in audio electronics, for example, to block bass notes, so you only hear treble.

Overall, you will learn to use the function generator and oscilloscope. You will also learn how "non-dimensionalize" data, such that it collapses onto a single curve. This is a particularly useful technique for experimental fluid mechanics and heat transfer.

Part I: High-pass Filter

In this portion of the lab, you will construct the RC circuit shown in Figure 1. You will then measure the peak-to-peak output voltage $|V_{out}|$ as a function of the driving frequency f. Copy the circuit diagram and table into your lab notebook.

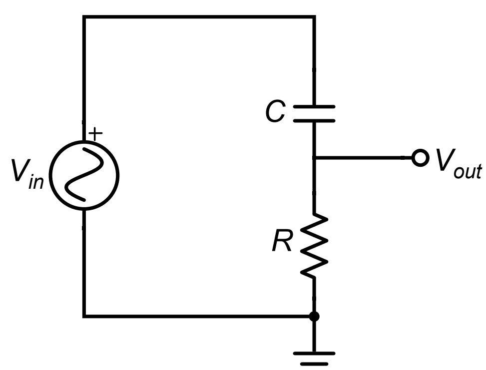

Figure 1 - High-pass filter circuit.

The *amplitude* of the AC output by the high-pass filter is given by the equation

$$|V_{out}| = \left(\frac{\omega RC}{\sqrt{1+(\omega RC)^2}} \right) |V_{in}| \quad (1)$$

where ω is the frequency in rad/s, R is resistance, C is capacitance, and $|V_{in}|$ is the amplitude of the input. Note that $|V_{out}|$ goes to zero as the frequency ω goes to zero, and it asymptotically approaches the input amplitude for high frequencies. Thus, the circuit *passes* high frequencies and blocks low frequencies.

The *phase* ϕ of the AC output relative to the input is given by the equation

$$\phi = \arctan\left(\frac{1}{\omega RC}\right) \tag{2}$$

The phase angle is directly proportional to time lag Δt between the two signals and can be calculated by multiplying by the frequency, i.e. $\phi = \omega\Delta t$.

Table 1a (R = 1 kΩ)		
f (kHz)	Amplitude V_{out} (pk-pk)	Phase Δt (s)
0.1		
1		
1.5		
2		
3		
5		
7		
10		

Table 1b (R = 2 kΩ)		
f (kHz)	Amplitude V_{out} (pk-pk)	Phase Δt (s)
0.1		
1		
1.5		
2		
3		
5		
7		
10		

1. Construct the circuit in Fig. 1 using R = 1 kΩ and C = 0.047 μF.
2. With the BNC-to-minigrabber cable, connect the ‘T’ on the output of the function generator to the circuit. Make sure the black minigrabber is connected to the grounded side of the resistor, and the red one is connected to the free lead of the capacitor.
3. Turn on the function generator. Press the “sine” button, then “output menu”, then “load impedance”, then “High Z”, then press “Top Menu” to exit to the main menu.
4. Connect the other side of ‘T’ on the function generator to CH1 on the oscilloscope (scope).
5. Set the output amplitude of the function generator to 10 V peak-to-peak and the frequency to 100 Hz. such that $V_{in} = (V_{pp}/2)\sin(2\pi ft)$.
6. With a different BNC-to-minigrabber cable, connect V_{out} to CH2 of the oscilloscope. Make sure the black minigrabber is connected to the grounded side of the resistor, and the red one is connected to the resistor-capacitor junction.

7. Be sure to press the "ON" button above the BNC T on the function generator.
8. Press the "auto set" button on the top of the oscilloscope. You should see two sine waves on you screen.
9. Press the "Measure" button at the top of the scope. Then, press "Add Measurement" in the bottom left corner. Use the "a" and "b" cursor knobs to add a peak-to-peak amplitude measurement for both CH1 (V_{in}) and CH2 (V_{out}). Press the "Menu Off" button once to clear the screen.
10. Measure the peak-to-peak amplitude of CH1 of the scope and record it in your lab notebook.

    Pro-Tip: The peak-to-peak amplitude measurement will not work if the waveform goes off the top or bottom of the screen.
11. Press the "Cursor" button near the top of the scope. Two vertical lines should appear on the screen. You will use the "a" and "b" cursor knobs to measure the phase Δt between the two waveforms.
12. Complete 1a in your lab notebook by varying the driving frequency f and recording the peak-to-peak *amplitude* of the output V_{out} of CH2 on the oscilloscope and the *phase,* Δt of CH1 relative to CH2. (Use the "measure" feature to determine the peak-to-peak *amplitude* and use the "cursors" to determine Δt of Channel 1 relative to Channel 2.)

    Pro-Tip: When measuring amplitude and phase, adjusting the **vertical scale** and **horizontal scale** will give you a more accurate measurement of amplitude and phase.
13. Change the resistor to R = 2 kΩ and repeat steps 4 – 10 to fill out Table 1b in your lab notebook.

Part II: Design a Filter

Design a filter that blocks frequencies below 50 kHz and passes frequencies above 50 kHz using circuit elements from the lab. Sketch a schematic of the circuit with the values you chose for the various circuit elements in your lab notebook. Measure the output amplitude V_{out} as a function of frequency f. Use at least 10 different frequencies between 1 and 100 kHz. Be sure to record the input amplitude V_{in}, as well.

Data Analysis and Deliverables

Please make the following plots in Matlab, import them into a LaTeX or MS Word document, and give them intelligent, descriptive captions. Make sure the axes are clearly labeled with units. Plots with multiple data sets on them should have a legend.

NOTE: In the lab all frequencies, *f* are in units of Hz and plotted on a linear scale.

1. A plot the measured output amplitude for the high-pass filter $|V_{out}|$ as a function of f with the theoretical equation plotted on top. Be sure to include a legend to distinguish between the data for R = 1 kΩ and 2 kΩ.
2. A plot of the measure phase angle ϕ as a function of f with the theoretical equation plotted on top. Be sure to include a legend to distinguish between the data for R = 1 kΩ and 2 kΩ. Be sure to convert the phase, Δt, into units of degrees by multiplying by the frequency f in Hz (i.e. $\phi = f\Delta t360$). Note that $-180 < \phi < 180$.
3. A plot of the *amplitude* data from the high-pass filter, but this time *non-dimensionalize* your data to be V_{out}/V_{in} as a function of $2\pi fRC$. This should *collapse* your data to a single curve. Plot the theoretical high-pass filter equation as a function of the non-dimensional parameter $2\pi fRC$ on top of the data.
4. A plot of the *phase* data from the high-pass filter, but this time *non-dimensionalize* your data by plotting phase in *radians* as a function of $2\pi fRC$. This should *collapse* your data to a single curve. Plot the theoretical high-pass filter equation as a function of the non-dimensional parameter $2\pi fRC$ on top of the data.
5. A plot of magnitude ratio V_{out}/V_{in} as a function of frequency f for the filter you designed in Part II. Include a vertical line at the cutoff frequency f_c = 50 kHz.

Appendix A

Equipment

- Tektronix AFG3021C Function Generator
- Tektronix MDO3012 Digital Oscilloscope
- Powered Breadboard
- Breadboard Solder-less Connectors
- BNC connector to red /black alligator clips – 2' length
- BNC Cables (qty. – 3) 3' – 4' in length
- BNC – "T" connector
- BNC connector - Red and Black banana end to BNC
- Resistors
- C = 47 nF Capacitor