Lab 3: RC High Pass Filter Experiment

Object: To explore the attenuation, phase-shifting, and transient behavior of an RC high pass filter circuit. This experiment involves resistance, capacitance, filtering, attenuation, half-power frequencies, loading, time constants, phase shifts, Lissajous figures, and oscilloscope and function generator operation.

Apparatus: HP 200CD Oscillator, Simpson 420 Function Generator, Tektronix TDS2004B Digital Oscilloscope, circuit chassis, resistor, capacitor, soldering station.

Introduction: The aim of this experiment is to test the reliability of the theoretical predictions for a RC high pass filter circuit like the one shown in Fig. 1. The prediction for the ratio of the amplitudes of the output voltage to the input voltage is

$$\frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{1+\left(f_o/f\right)^2}} , \qquad (1)$$

The half-power angular frequency, f_o, is given by $f_o = 1/2\pi RC$. The theoretical prediction for the phase shift between in output and the input voltages is

$$\phi = \tan^{-1}\left(\frac{f_o}{f}\right). \qquad (2)$$

Exercise:
1. Begin by constructing the high pass filter circuit shown in Fig. 1 into the circuit chassis. Have your instructor check your solder technique and your circuit layout.
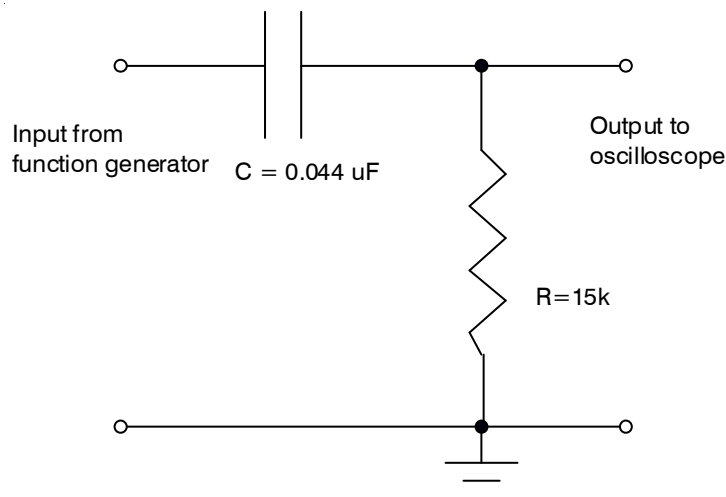

FIG. 1 RC High Pass Filter Circuit

2. Connect the HP 200CD Oscillator to the circuit input and to the CH1 input on the TDS2004B oscilloscope (using a BNC 'T'). Connect the circuit output to the CH2 input on the scope. Set the probe attenuation settings for both input channels to 1X. Trigger on CH1 (AUTO, Rising Slope).

3. Proceed to acquire input-output data that lets you test the theoretical predictions given by Eqs. 1 and 2 above. Your amplitude data should consist of pairs of voltage values (V_{in}, V_{out}) acquired at 30 or so frequencies ranging from $f_o/20$ to $50f_o$ where f_o is the half-power frequency $f_o = 1/2\pi RC$. We suggest that you acquire "peak-to-peak" rather than "peak" amplitude measurements. You may take advantage of the TDS2004B oscilloscopes frequency and measurement capabilities, but verify those measurements directly for some of your data points. To measure the phase shift, we recommend "zooming" in on the zero-crossings and measuring the time delay between the signals on the two channels (using the cursor function on the TDS2004B). From the frequency (or period) and the time delay, you can calculate the phase shift (in radians or degrees).

4. Plot V_{out}/V_{in} versus f using Kaleidagraph (or some other graphing program) giving each point an appropriate error bar. Compare the experimental data to the theoretical predictions by using Kaleidagraph's nonlinear curve fitting feature with the half-power frequency as a fit parameter. Ask your instructor if you need help writing the fit function. Does the fit parameter associated with the half-power frequency agree with the prediction within the uncertainties? The resistor and the capacitor both have uncertainties (what are they?), as does the half-power frequency obtained from the nonlinear fit.

5. Also plot the phase shift versus f in order to test the theoretical prediction from Eq. 2. Generate a fit function with the half-power frequency included as a fit parameter. Compare the half-power frequency obtained from this fit to the one obtained from the amplitude graph and to the predicted value given the resistor and capacitor values. Pay attention to uncertainties.

6. **Lissajous Figures:** There is another technique for making phase shift measurements that makes use of the oscilloscopes ability to display the signal on CH2 vs. the signal on CH1. This is called X-Y display mode as opposed to Y-T display mode. This feature is accessed from the DISPLAY menu → Format set to XY. Scan the range of frequencies explored in the previous sections and make a few sketches in your notebook to indicate how the display changes as a function of frequency. Think carefully about the appearance of the display. How can you determine the phase shift from this way of displaying the signals? You do NOT need to make measurements at all frequencies again.

7. **Loading Effect:** Replace the 15kΩ resistor with a 1kΩ resistor, and note that as the frequency of oscillator is increased the *amplitude* of its output signal "droops". Does this drooping of the function generator's output amplitude make sense in terms of the larger currents being drawn from the function generator by your circuit at higher frequencies? Given that the oscillator's internal resistance is 600 Ω, why is this "drooping" or "loading" effect accentuated by the use of the 1 kΩ resistor? This exercise shows that

one should always measure both the output *and* the input amplitudes when acquiring circuit data as in this experiment.

8. **Transient Behavior:** Construct the circuit shown in Fig. 2. Use the Simpson 420 Function Generator to produce a 5 V *square* wave at 1 kHz. Use the DC OFFSET knob to make it go from 0V to +5V. Determine the time constant for the exponential rise (time to 63% of maximum) and fall (time to 37% of minimum) and compare to the theoretical prediction that $\tau = RC$.
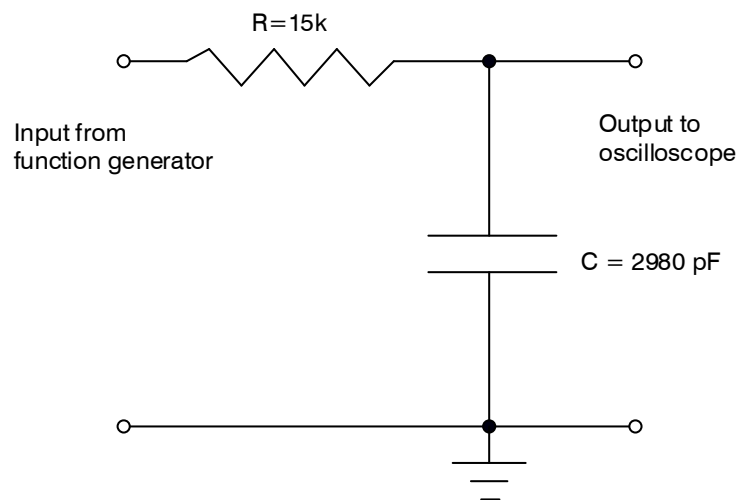
R=15k

Input from
function generator

Output to
oscilloscope

C = 2980 pF

FIG. 2 RC circuit used to demontrate transient behavior and time constant measurements.