Instructional Objectives (at the end of this lab you should be able to:)
- Understand the numerical coding used for capacitor values.
- Create circuits on the prototype board consisting of resistors and capacitors.
- Use the lab function generator to create sinusoidal signals at specified frequencies.
- Measure AC voltage amplitudes using the oscilloscope.
- Understand that signal frequency affects circuits with capacitors.
- Plot results on a semi-log scale graph.

Description and Background

Capacitors can store electrical charge depending on the size (capacitance) of the capacitor. The capacitance is measured in farads: coulombs (charge) divided by volts. Typical capacitors found in the lab might be 1.0 microfarads (10^{-6} farads), or 0.1 microfarads, or 0.001 microfarads.

Capacitors are frequently labeled with a three digit code that is somewhat similar in format to the code for resistors. Referring to the three digit sequence as ABD, the nominal value of the capacitor is given by A:B x 10^D in picofarads (pF). For example, the label "103" (A=1, B=0, D=3) would mean 10 x 10^3 pF, or 0.01 µF (microfarads).

The three digit nominal value code is usually followed by a letter, which is used to indicate the *tolerance* of the capacitance value. Common tolerance indication letters are: M=20%, K=10%, J=5%, G=2%, F=1%, and E=0.5%. Recall that the tolerance refers to what range of actual (measured) capacitance is expected for the particular device, expressed as a ± percentage of the nominal value. For example, if a capacitor is labeled "103K", that means its capacitance will be somewhere in the range 0.01 µF ± 10%, or between 0.009 µF and 0.011 µF.

Applications of capacitors include using them in circuits, along with resistors, to create electrical *filters*. Filters will tend to reduce the amplitude of electrical signals in selected frequency ranges. For example, a *lowpass filter* will allow low frequency signals to pass through the circuit without affecting the amplitude, but will reduce the amplitude of high frequency signals. Thus, the output signal from a filter circuit which is supplied by a sinusoidal input signal will have amplitude that depends on both the amplitude and frequency of the input signal. For example, a low pass filter is found in a stereo or radio "tone" control setting: adjusting this control can cause an increase in the level of bass (low frequency) sounds relative to high frequency sounds.

In this experiment you will explore the characteristics of simple lowpass filters made using one resistor and one capacitor. At low frequencies, the capacitor will have sufficient time to become "charged" during one half cycle of the sinusoidal input signal and produce an output. At very high frequencies, the *period* (cycle duration, 1/frequency) of the input signal is so short that the capacitor cannot charge or discharge before the next cycle of the waveform. This means that the output amplitude is expected to decrease as the input frequency increases.

Resistor-capacitor circuits are characterized by the *RC time constant*, which is the product of the resistance (in ohms) and the capacitance (in farads). This RC time constant (often denoted τ) has the

units of seconds, and represents the amount of time required for the capacitor to charge to within 1/e of its final value, or discharge to 1/e of its starting value, where "e" is the base of the natural logarithms (e ≈ 2.71828…, so 1/e ≈ 0.368). The reciprocal of the RC time constant (1/RC) has the units of "radians per second," or $2\pi f$. To determine the corresponding frequency, f, in Hz, divide 1/RC by 2π. The frequency f = $1/(2\pi RC)$ provides an indication of the frequency by which the lowpass filter is noticeably reducing the amplitude of the input signal. We often refer to $1/(2\pi RC)$ as the "break frequency" that separates the low and high frequency ranges of the RC circuit.

Equipment
Your own circuit prototype board, your own lab kit containing the required components and alligator clips, your own resistor color code chart, and the bench signal generator, oscilloscope, and banana cables furnished in the lab for connecting the instruments.

Procedures
P1. Construct the circuit shown in Fig. 1 on your prototype board. Use the lab signal generator to provide the input voltage, which is a sinusoidal signal. Start with the frequency set to about 500 Hz. Use the oscilloscope to observe the input signal: connect the probe tip to the positive (red) lead from the signal generator, and the probe's ground clip to the ground (black) lead from the signal generator. Adjust the signal generator amplitude to be exactly 2 V peak-to-peak by observing the waveform on the oscilloscope while you turn the amplitude knob on the signal generator.

Now move the oscilloscope probe to observe the peak-to-peak voltage of the signal V_{out}. To do this, leave the ground clip connected where it is and just move the probe tip over to the node between the resistor and the capacitor.
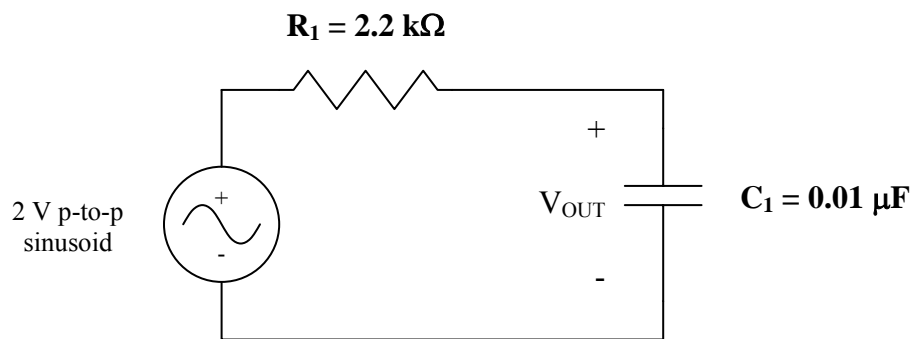
Figure 1: RC Circuit for P1

→ Adjust the frequency of the signal generator to each of the frequencies specified in the table on the next page, and record your measurements for V_{out}, including the proper <u>units</u> (e.g., amperes or volts?), in column 3. Occasionally verify that the input remains at 2 V peak-to-peak.

Input Frequency	Input Amplitude (set 2V peak-to-peak)	V_{OUT} Amplitude for Fig. 1 (peak-to-peak)	V_{OUT} Amplitude for Fig. 2 (peak-to-peak)
500 Hz			
1 kHz			
2 kHz			
5 kHz			
7 kHz			
10 kHz			
20 kHz			
30 kHz			
50 kHz			
70 kHz			
100 kHz			
150 kHz			
200 kHz			

P2. Construct the circuit shown in Fig. 2 on your prototype board. Note that you just need to replace the capacitor with a 3.0 kΩ resistor.

→ With the input signal amplitude set for 2 V peak-to-peak, connect the oscilloscope to measure V_{out} peak-to-peak for the range of input frequencies specified in the table. Record your measurements in column 4 of the table including the <u>units</u>.
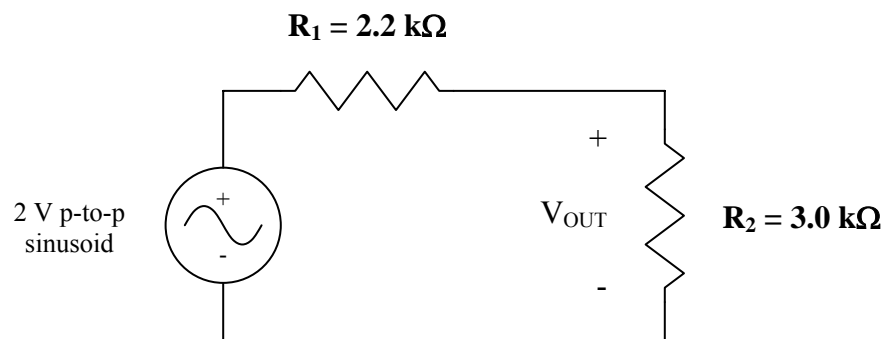
R₁ = 2.2 kΩ

2 V p-to-p
sinusoid

V_{OUT}

R₂ = 3.0 kΩ

Figure 2: RR Circuit for P2

P3. → Carefully plot by hand the data points you have measured (peak-to-peak amplitude on the vertical axis vs. frequency on the horizontal axis) on a <u>semi-log scale</u> graph (see next page). Plot the data from P1 and the data from P2 on the same sheet, clearly indicating which is which using different colors or data markers.

→ Also draw on your graph a vertical line corresponding to the "break" frequency for the RC circuit of P1, which is proportional to the reciprocal of the RC time constant. Be sure to change from radians/second to Hz frequency units: $f_{break} = 1/(2\pi RC)$.

→ Write a descriptive <u>graph title</u> on the plot and include <u>axis titles, labels, and units</u>.
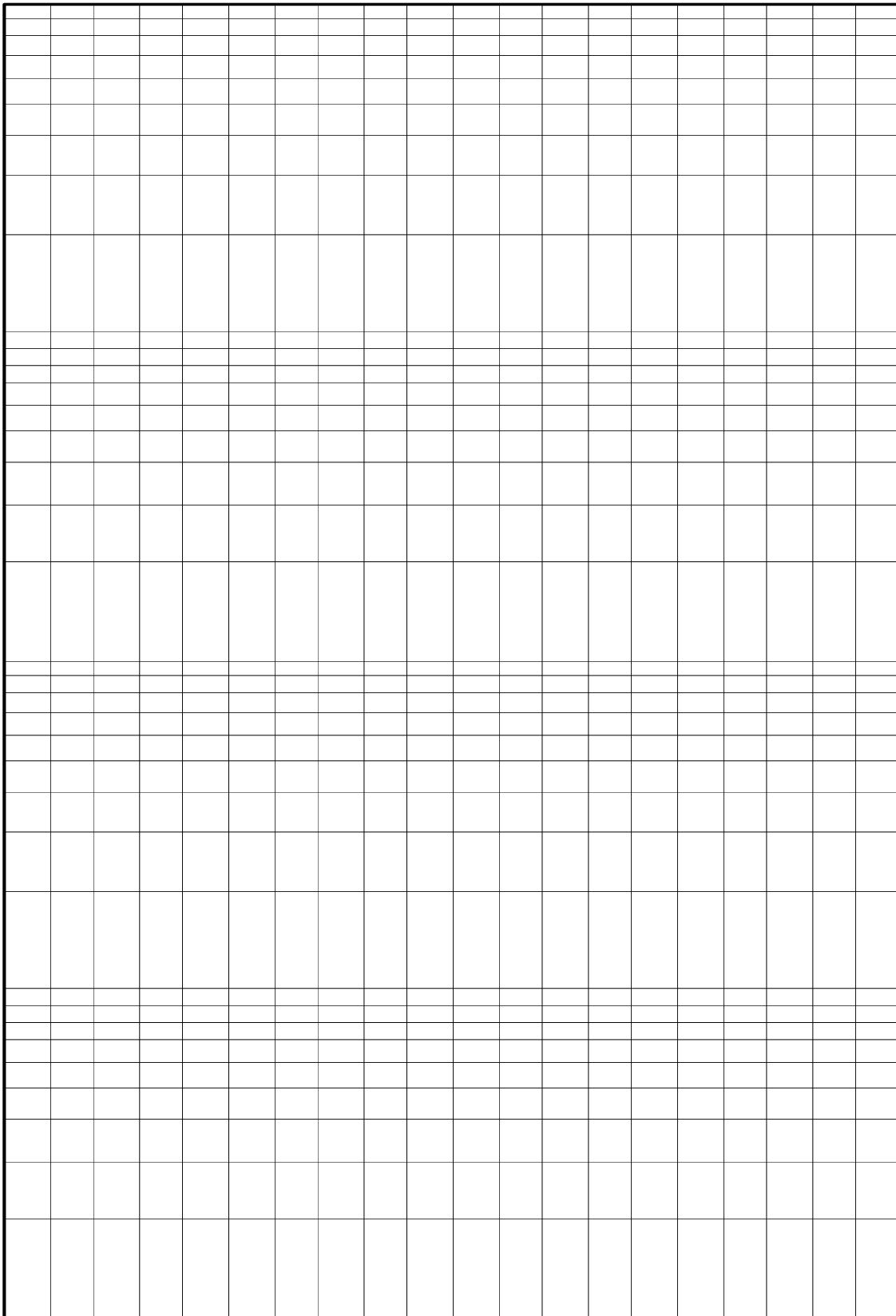
← Four Cycle Semi-Log →

P4. Explain, using complete sentences, why your results show a "filter" characteristic for the circuit of Fig. 1. Comment on the "break" frequency with respect to the graphed data.

How is the graph for the measurements from Fig. 2 different from the graph for the circuit of Fig. 1? Give a written description of how you interpret the "filter characteristic" for the measurements from Fig. 2, using complete sentences.

P5. What would be the general effect on the graph results for the circuit of Fig. 1 if you were to change the capacitor in the circuit of Fig. 1 to be 0.1 µF instead of 0.01µF? Think about the time constant, RC. Explain why it is not actually necessary to complete a full set of measurements for this change (however, you may want to take a few measurements to confirm the effect of this change). .