EE101 Laboratory 4 **(SP03)** **Name ______________________________**

Date ______________________ **Partner's name ______________________________**

Instructional Objectives (at the end of this lab you should be able to:)

- Measure the period of sinusoidal signals using the oscilloscope.
- Calculate the frequency of sinusoidal signals from oscilloscope measurements of the period.
- Simultaneously display two channels of sinusoidal signals on the oscilloscope.
- Use the oscilloscope to make differential voltage measurements.
- Measure phase differences between voltage and current in a resistor-capacitor circuit.

Description and Background

Signal *frequency* refers to the number of cycles per second of a periodic signal. Frequency is expressed with units of hertz (Hz). A *periodic signal* is one in which each cycle is identical, and the signal consists of repeating cycles. Measuring the *period* (T) of a signal can be accomplished using the oscilloscope, and requires reading the horizontal distance in *divisions* (the grid lines on the display) and multiplying the number of divisions by the "time-per-division" horizontal scale. The horizontal scale is adjusted with the horizontal knob, and the time-per-division scale factor is displayed next to the "M" on the lower part of the oscilloscope screen.

Accurate measurements of time (horizontal axis) are accomplished by either of two methods. One is to adjust the time scale so that only one cycle extends over most of the horizontal axis of the view screen, and then read the time axis accurately for this one cycle. The other approach is to show multiple cycles on the screen, and then accurately read the time axis for an integer number of several periods. The time for one cycle is then found by dividing the total time for several cycles by the number of cycles over which the measurement was taken.

By measuring the waveform period with the oscilloscope, we can calculate the corresponding frequency of that waveform. Frequency in Hz is the *reciprocal* of the waveform period: $f = 1/T$. For example, if the waveform period (time interval for one cycle) is measured to be 0.02 milliseconds, then the signal frequency is (1 cycle) divided by (2×10^{-5} seconds), which is 50,000 cycles/second, or 50 kHz.

Phase refers to the time relationship of one sinusoidal signal to another. For example, a sine wave expressed mathematically as $sin(300t)$ has a phase shift of 90 degrees relative to a cosine wave expressed as $cos(300t)$. Note that phase relates two signals at the same frequency; two signals with different frequencies do not have a constant phase relationship.

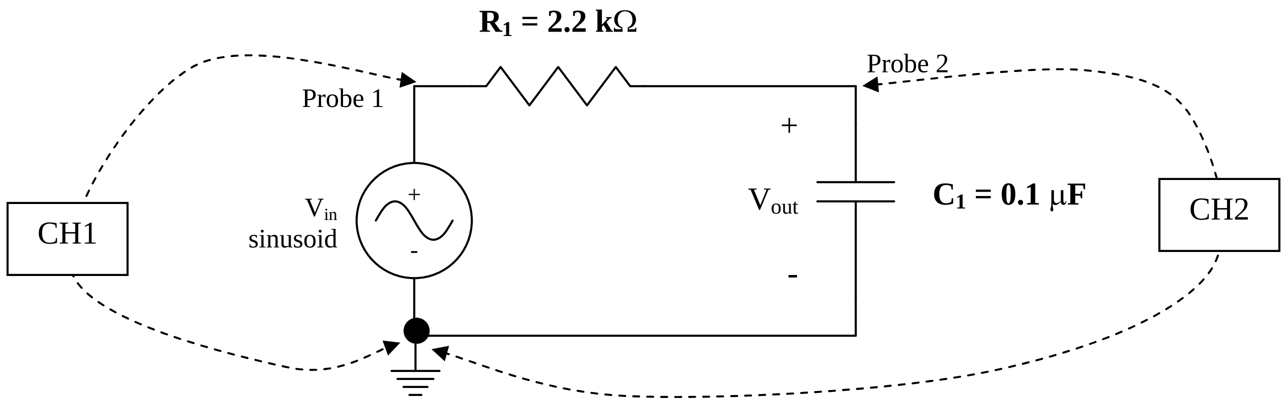
Electrical circuit analysis shows that the current through a resistor is *in phase* with the voltage across that resistor, whereas the current through a capacitor is *not in phase* with the voltage across the capacitor. This is because the capacitor voltage depends on the amount of charge that has been delivered to the capacitor, and this requires the current (charge per second) to occur before the voltage, since the amount of charge depends upon the integral of the current: (charge per second) × seconds = total charge stored).

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 RC circuit shown below on your prototype board.



? Indicate and verify the capacitor labeling and show how you calculate the nominal capacitor value.

Capacitor Label (3 digit code and letter): ________________

Nominal Value and Tolerance (show the formula): ______________

(Verify that this is equal to 0.1 μF, as required in the circuit.)

Use the lab signal generator to provide the input voltage, which is a sinusoidal signal. Set the generator frequency to $\boxed{\text{1.25 kHz}}$.

Observe the signal generator voltage using Channel 1 of the oscilloscope, and adjust the generator voltage amplitude to a reasonable value of your choice (1 V peak-to-peak would be good).

Connect Channel 2 of the oscilloscope to display the voltage signal V_{out}. Adjust the vertical and horizontal scale knobs on the oscilloscope so that both waveforms are clearly visible and occupy as much of the display screen as possible. The optimum vertical scale settings for the two channels may be different! Also adjust the vertical *position* knob so that both waveforms are evenly centered up and down on the center horizontal line of the screen.

? Record your measurements in the table below for the three listed input frequencies from the signal generator. Show your measured horizontal and vertical divisions (divs.), and calculate the results *including the proper units!* Remember: *period* and *frequency* are inversely related.

Signal Generator Frequency	**V_{in} peak-to-peak:** (number of vertical divisions × CH1 volts per division)	**V_{out} peak-to-peak:** (number of vertical divisions × CH2 volts per division)	**Waveform Period, T:** (number of horizontal divisions × time per division)	**Calculated frequency in Hz:** $\frac{1}{T}$
1.25 kHz	CH1 # vert. divs.: _______ volts/div.: _________ result: ____________	CH2 # vert. divs.: _______ volts/div.: _________ result: ____________	# horiz. divs.: ______ secs/div.: _________ result: ____________	
2.50 kHz	CH1 # vert. divs.: _______ volts/div.: _________ result: ____________	CH2 # vert. divs.: _______ volts/div.: _________ result: ____________	# horiz. divs.: ______ secs/div.: _________ result: ____________	
5.00 kHz	CH1 # vert. divs.: _______ volts/div.: _________ result: ____________	CH2 # vert. divs.: _______ volts/div.: _________ result: ____________	# horiz. divs.: ______ secs/div.: _________ result: ____________	

P2. Now set the signal generator frequency to be $\boxed{\text{1 kHz}}$.

? Measure and record the *period* (one cycle) for either of the displayed signals. Note (if you haven't already!) that both CH1 and CH2 will have the same period since there is just one signal generator present in this circuit.

Signal Period (T [seconds]): _______________

? Measure and record the time interval *between* the two signals. In other words, determine how much delay is present between a corresponding feature (peak, zero crossing, etc.) of CH1 and CH2.

Signal Delay (?t [seconds]): _______________

? Which signal, V_{in} or V_{out}, *leads* the other in time? Describe, using full sentences, why you say this is so.

The ratio of Δt and T, found by dividing the time interval between the two signals by the time for one period, is the phase fraction of 360 degrees (360 degrees covers one sinusoid cycle).

? Calculate the relative phase in degrees by multiplying the $\frac{\Delta t}{T}$ ratio by 360. In other words, the phase is given by $\theta = (\Delta t/T)*360^o$.

Relative Phase (T [degrees]): ______________

P3. The two 'scope channels connected as above allow measurements of the voltage across the function generator (CH1 = V_{in}) and the voltage across the capacitor (CH2 = V_{out}), but the voltage across the resistor V_{R1} is not yet measured. Neither end of R_1 is connected to the "ground" of the circuit, so unfortunately we cannot just hook one of the oscilloscope channels across R_1 in order to measure V_{R1}.

Instead, note that V_{R1} is equal to V_{in} *minus* V_{out}, using Kirchhoff's Voltage Law (KVL). The oscilloscope is able to display V_{in} minus V_{out} using the "math" functions. Select the subtraction (difference) option for CH1 – CH2 using the Math Menu on the oscilloscope panel.

Verify that the function generator is still set for 1kHz.

? Measure and record the peak-to-peak voltage V_{out} across the capacitor, including the proper unit.

V_{out} (p-to-p [volts]): ____________

? Measure and record the peak-to-peak voltage V_{in} across the function generator, including the proper units.

V_{in} (p-to-p [volts]): _____________

? Measure and record the peak-to-peak voltage V_{R1} across the resistor using the two-channel difference method described above; including the units.

V_{R1} (p-to-p [volts]): ____________

? Calculate the phase in degrees between V_{R1} (CH1-CH2) and V_{out} (CH2) using procedures similar to those you used in P2. Which signal leads the other in time?

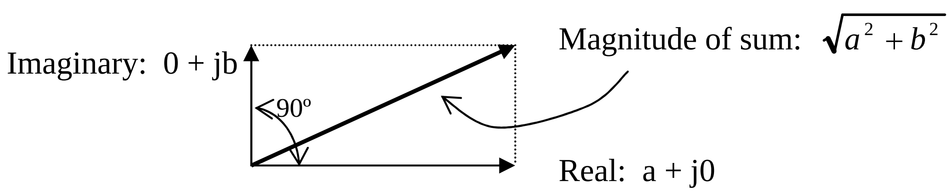
Relative Phase, V_{R1} and V_{out} (T [degrees]): ______________ Which leads?

P4. Notice that it will NOT work to apply KVL simply by adding the *peak-to-peak* signal amplitudes around the loop, since the sinusoidal signals are *not* in phase with each other: the peaks do not line up in time, so summing the peak values doesn't make sense.

? To check this out, write an expression for KVL for the circuit using the peak-to-peak values of V_{in}, V_{R1}, and V_{out}. Does the KVL expression *using peak-to-peak values* work out? Explain.

P5. In order to get a proper KVL relationship for this circuit, we must take into account the phase differences between the signals. Since the current *leads* the voltage in the capacitor by 90 degrees, and the capacitor current is equal to the resistor current (R and C are in series), we expect that V_{R1} and V_{out} differ by 90 degrees.

To add two numbers that differ by 90 degrees, we treat their magnitudes as *complex* numbers and use the theorem of Pythagoras:



? Apply this principle to the voltages measured for V_{R1} and V_{out} to calculate an estimate for the generator voltage. Draw a real-imaginary sketch (like above). Plot your measured capacitor voltage (V_{out}) peak-to-peak magnitude along the real axis ("a"). Plot the resistor voltage (V_{R1}) along the imaginary axis ("b"). Calculate the expected value for the generator voltage magnitude using the measured resistor and capacitor voltages and complex addition. Show your work.

? Is the calculated value nearly the same as the value you measured for V_{in}? Find the percentage difference between this calculated value and the measured value for the voltage across the function generator.