

# Physics 310

## Lab 3 – AC Circuits

**Equipment:** o'scope, function generator, transformer, multimeter, capacitance meter, BNC-T, BNC cable, BNC-banana converter, BNC-alligator cable, banana cables, 1 k, 10 k, 7mH, ½ Watt – 100Ω, 22μF, 0.01 μF

### General Lab Notebook instructions (from syllabus)

You should be sure to write down enough so that you can recall what you did several weeks later (it may come in handy when you're working on your final project.) The following information should be included:

1. Titles for labs and sections of labs.
2. Description of procedures followed (e.g. what was measured).
3. Well-labeled diagrams of circuits.
4. Record of observations and data (in tabular form when appropriate).
5. Analysis of data: computations and tables or graphs of results.
6. Comparison with theory: calculations and graphical or tabular comparison.
7. Answers to all questions.

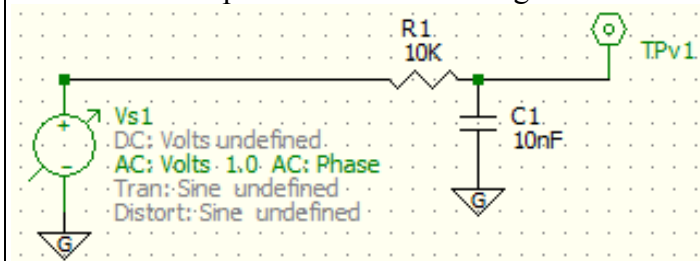
### General Procedures:

- Connect a T to the output of the function generator and a cable from that to the input for Channel 1 of the oscilloscope. Use Channel 2 for viewing the output of the circuits you build.
- Capacitances and inductances may vary significantly from specified values. Use the RLC meter to measure them rather than using the nominal values in your calculations.
- It is not necessary to plot theoretical fits to your data for the filter circuits. Instead, use the data to determine the break-point frequency or the resonance frequency (whichever is relevant).

### 3-1. Low-Pass Filter

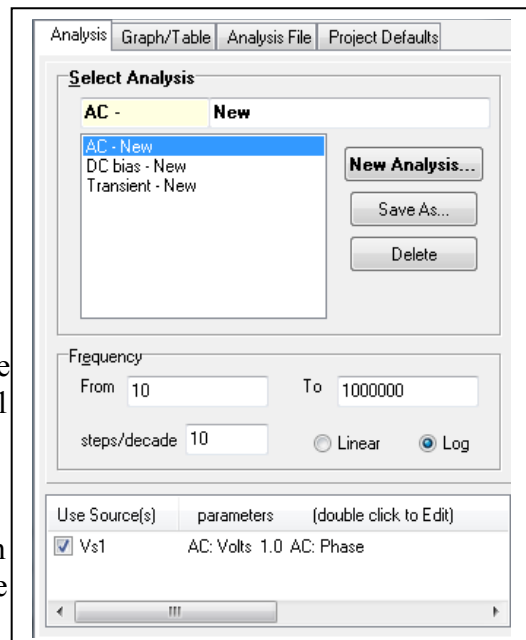
**A. Pre-Lab.** (answer questions on a separate sheet so that during lab you can affix your work into your notebook where appropriate.)

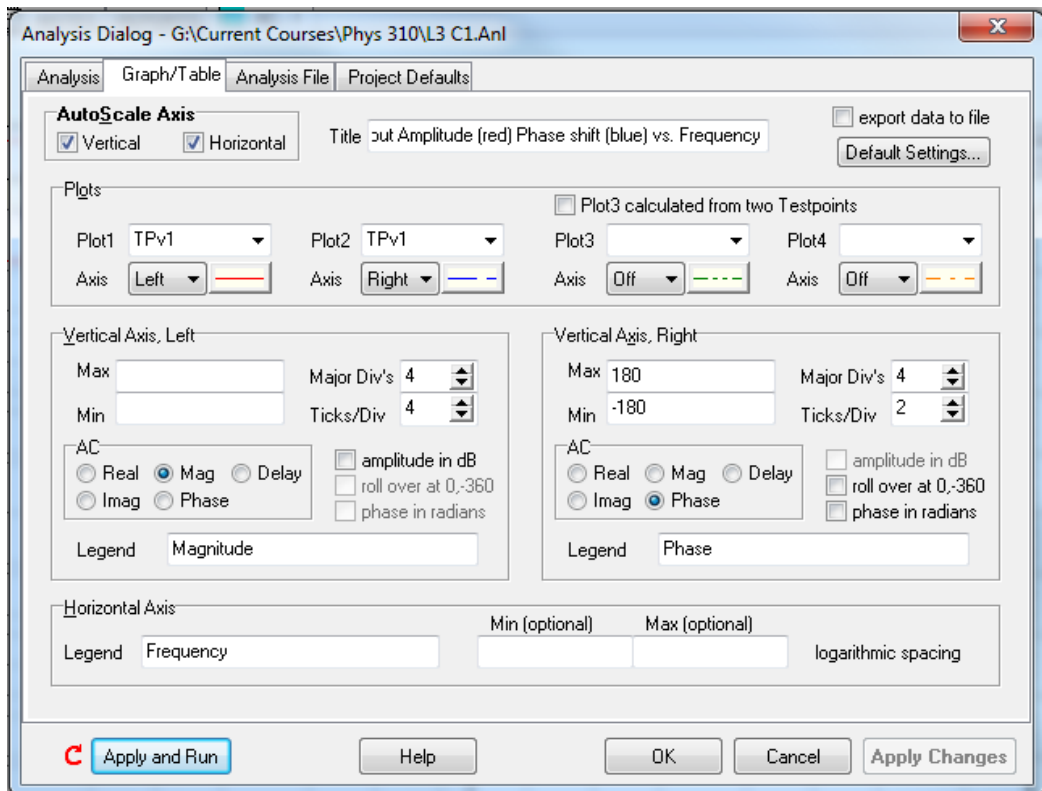
1. In 5Spice build the following circuit and set up the analysis as shown.



**Question:** According to the relation given in the text, what should be the 'break-point' frequency for this circuit (given the  $R_1$  and  $C_1$  values)?

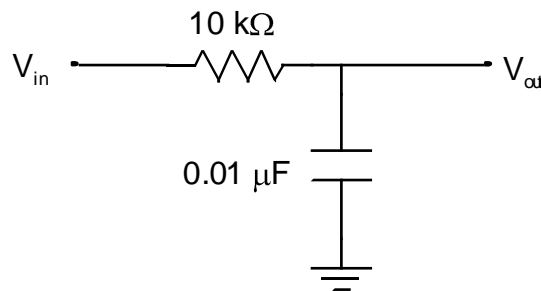
2. You'll analyze how both the amplitude and the phase of the output (TPv1) depend on the supply's frequency over the range 10 Hz to 1 MHz. To plot both the output's amplitude and phase shift (relative to the phase of the input), in the "Graph/Table" tab of the Analysis dialog box, make the entries shown on the next page (some will automatically be made for you).





3. Hit the “Apply and Run” button to make the plots.
4. Observe that you can slide a vertical cursor to read off the values of magnitude or phase shift for different frequencies.  
**Question:** Use the graphs to determine the “break-point” frequency, that is where  $(V_{out}/V_{in}) = \frac{1}{\sqrt{2}} = 0.707$  and  $\phi = -\frac{\pi}{4} = -45^\circ$ . How does this compare with the frequency you’d expect based on the relation given in the text?
5. Save the circuit to a thumb drive or email it to yourself so you can open and modify it in lab.

B. Construct the following circuit.



- C. Input a sine wave and measure the gain ( $A = V_{out}/V_{in}$ ) and the phase angle of the output with respect to the input as functions of frequency from 10 Hz to 1 MHz in decade intervals (10, 100, etc.). Also be sure to take a couple of data points in the vicinity of the expected break-point frequency:  $1/(2\pi RC)$ .
  1. Note: The function generator’s output (your circuit’s  $V_{in}$ ) may change with frequency, so you’ll need to measure it as well as  $V_{out}$  for each frequency.
  2. Note: You need the O’scope to be in DC mode since AC mode employs an internal high-pass filter that could confuse your measurements; however, you may wish to

switch back to AC at particularly high frequencies since your output may develop an offset.

3. Note: At a given frequency,  $\omega = 2\pi f$ , the phase angle is  $\phi = -\omega \cdot \Delta t$ , where  $\Delta t = t_{out} - t_{in}$  is the time offset between when the input and output signals hit a certain phase (say, peaks or crosses 0).

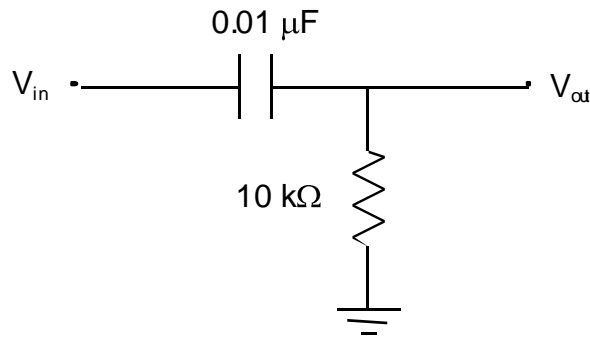
- D. Plot the gain and phase angle vs. the log (base 10) of the frequency. Use the graphs to determine the break-point frequency where  $A = \frac{1}{\sqrt{2}} = 0.707$  and  $\phi = -\frac{\pi}{4} = -45^\circ$ .

**Question:** How do the measured and expected values of the break-point frequency compare (% difference)? To determine the “expected” values, use the *actual* resistance and capacitance values either in the theoretical equation or in 5Spice.

### 3-2. High-Pass Filter

A. **Pre-Lab.** Swap the capacitor and the resistor in the 5Spice simulation and perform the same analysis as before. Again, use the graphs to determine the break-point frequency.

B. Construct the following circuit.



- C. Input a sine wave and measure the gain and the phase angle of the output with respect to the input as functions of frequency from 10 Hz to 1 MHz in decade intervals. Again, make sure to take points in the vicinity of the expected break-point frequency.

- D. Plot the gain and phase angle vs. the log of the frequency. Use the graphs to determine the break-point frequency where  $A = 0.707$  and  $\phi = +45^\circ$ .

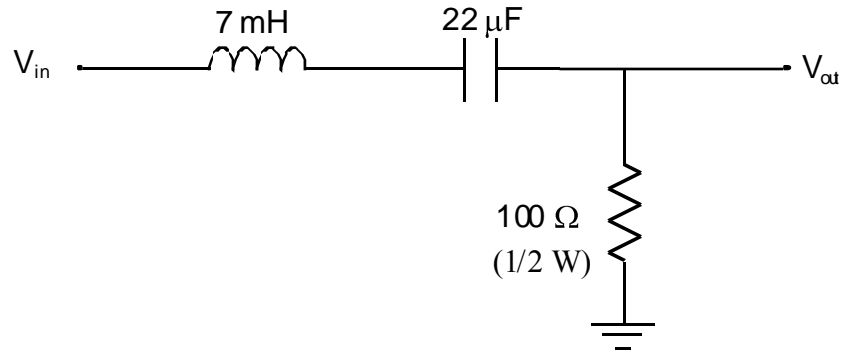
**Question:** How do the measured and expected values of the break-point frequency compare (% difference)? To determine the “expected” values, use the *actual* resistance and capacitance values either in the theoretical equation or in 5Spice.

### 3-3. Band-Pass Filter (or Resonance)

A. **Pre-Lab.** Modify your circuit in 5Spice to model that illustrated below (note  $22\mu\text{F} = 22000\text{nF}$  and  $100\Omega$  would simply be “100” in the simulation.)

**Question:** According to your plot, what is the resonance frequency (at which the output signal is largest), and what is the phase shift at that frequency?

B. Construct the following circuit.



C. Input a sine wave and measure the gain of the output with respect to the input as functions of frequency between 10 Hz and 1 MHz. You should take more measurements in the range where changes are most dramatic and around the expected resonance

$$\text{frequency, } f_0 = \frac{1}{2\pi\sqrt{LC}}.$$

D. Plot the gain vs. the log of the frequency. Use the graph to determine the resonant (or natural) frequency where the gain is maximum.

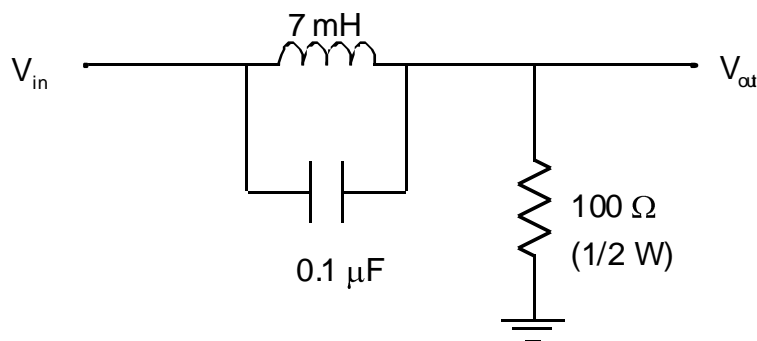
**Question:** How do the measured and expected values of the resonant frequency (based on the *measured* values of resistance, inductance, and capacitance) compare (% difference)?

**3-4. Notch Filter** – This type of circuit can be used to filter out a very narrow range of frequencies. The one you will build blocks a fairly wide range of frequencies so that its behavior is easier to study.

A. **Pre-Lab.** Modify your circuit in 5Spice to model that illustrated below (note  $0.1\mu\text{F} = 100\text{nF}$  and  $100\Omega$  would simply be “100” in the simulation.)

**Question:** According to your plot, what is the notch frequency (at which the output signal is *smallest*), and what is the phase shift at that frequency?

B. Construct the following circuit.



C. Input a sine wave and measure the gain as a function of frequency between 10 Hz and 1 MHz. You should take more measurements in the range where changes are most dramatic.

D. Plot the gain vs. the log of the frequency. Use the graphs to determine the notch frequency where the gain is.

**Question:** How do the measured value of the notch frequency and the expected value of

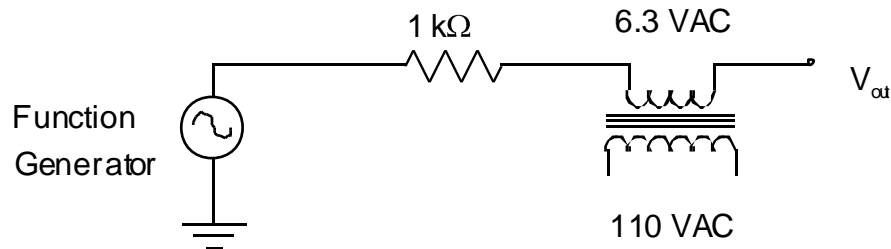
$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

compare?

### 3-5. Applications

#### E. Removing Noise from a Signal

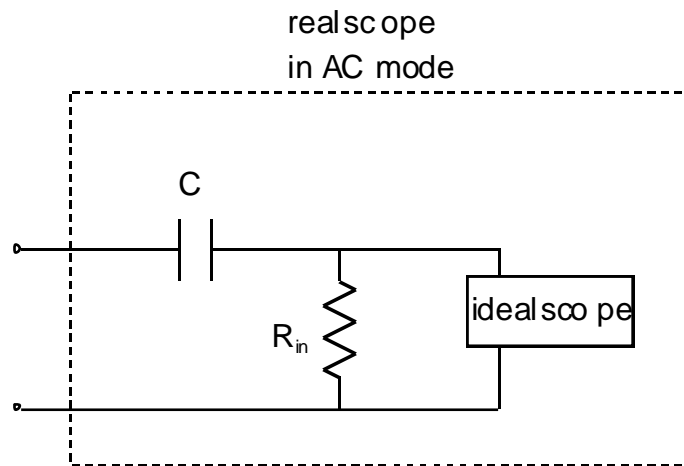
1. The circuit shown below will produce an output that is a combination of sine waves with frequencies of 60 Hz (from the transformer) and whatever frequency the function generator is set at. Adjust the function generator to produce a sine wave with a frequency of 10 kHz and a small amplitude.



2. Suppose the 60-Hz part of the waveform is “noise”, which is common because most devices are plugged into outlets supplying 60-Hz current. Design and build a filter to remove most of the 60-Hz part of the signal, but not much of the 10-kHz part.

#### F. Understanding the AC mode of an Oscilloscope

1. When an oscilloscope is switched to AC mode, low frequency components of a signal are filtered out. (The DC offset of a signal has “zero frequency”.) This is accomplished by adding a capacitor to the oscilloscope’s input. Recall that the oscilloscope also has an input resistance, so in AC mode it looks like the following.



2. Adjust the function generator to produce a 10-Hz square wave. Look at the signal on an oscilloscope in DC mode, then in AC mode. Describe how the signal looks in AC mode.

**Question:** Why does the AC mode affect the signal in the way it does? (Hint: What does the signal in AC mode remind you of from the last lab?)

### **3-6 Band-Pass Filter**

- G. Connect the output of the low-pass filter of exercise 3-1 to the input of the high-pass filter of exercise 3-2.
- H. Input a sine wave and measure the gain as a function of frequency from 10 Hz to 1 MHz in decade intervals.
- I. Plot the gain vs. the log of the frequency.

**Question:** Approximately what range of frequencies passes through the filter with little attenuation?