Introduction to Analog Electronics

Preparation: Before coming to lab, read this guide and *Melissinos* **Chapter 3 sections 3.1 – 3.4. Answer exercises 3, 4, and 5 on pp502-503 in** *Melissinos***. Then answer the numbered questions in bold face that appear throughout this lab guide. Answers to these pre-lab questions are to be handed in at the beginning of your lab. Be sure to bring to lab: this guide, your lab notebook, a ruler, a calculator. Sheets of log-log graph paper are included at the end of this guide and will be also be available in the lab. Also,** *in advance of the lab* **read the tutorial on** <u>oscilloscopes</u> **on the 122 electronics lab webpage [you will not have time to come up to speed during the lab], and explore various RLC circuit behaviors using the Java applet.**

Post Lab Questions: At the beginning of this lab section, you will be given an additional handout with a series of questions to be answered and handed in at the end of the experiment. Try to answer these questions with one or two concise sentences.

Background: *Resistors*, *capacitors*, and *inductors* are ubiquitous components in practically every electronic circuit. Their combinations and applications are endless and limited only by the imagination of the circuit designer. Two very common applications are (1) filters and (2) oscillators. Electronic filters can be used to let only high frequency signals pass through while suppressing the low frequencies (like the treble control on your stereo), to let only low frequencies through while suppressing the high ones (bass control), and to remove noise from an electrical signal (sometimes call noise suppressors) There are many more examples of filter applications. Electronic oscillators are analogous to the mechanical simple harmonic oscillators you have come to know. Both are described mathematically by sinusoidal functions. The phenomenon of resonance is a behavior common to both, and there are countless applications that use this phenomenon to select a particular frequency (radio and TV signals, for example). When you select a radio station or TV channel, you are using electronic oscillators. In this lab you will use resistors, capacitors, and inductors in circuits to create some filters and oscillators.
At the end of this analog electronics lab, and before you start the pulse propagation electronics lab, you will be given a 20-400 pF variable capacitor and a 150 µH inductor with which you will build a tunable filter of the sort you have in a radio in the AM band.

Experimental Setup: A function generator will supply a sinusoidal voltage to RC, RL, and RLC series circuits. This function generator is tunable over a wide range of frequencies up to ~1MHz. The oscilloscope will be used to measure the voltage across a resistor and thus monitor the instantaneous current flowing in the circuits as a function of time.

Objective: In this experiment you will study the frequency dependence of inductive and capacitive reactance. You will learn to use an oscilloscope, a powerful and versatile tool used to study electrical circuits.

Theory

Resistors limit the current that can flow in a circuit. Just as a kink in a garden hose limits the amount of water per unit time that can flow through the hose, a resistor limits the amount of charge per unit time (current) that can flow through a wire. This property of resistors is independent of time. A given resistor offers the same resistance to both dc and ac currents.

The same is not true for other circuit elements. In this lab, we will study the "resistance," called "reactance", of capacitors and inductors. This reactance occurs only with time varying currents, not dc currents. The reactance of a capacitor is

$$X_C = \frac{1}{2\pi f C}.$$

And the reactance of an inductor is

$$X_L = 2\pi f L.$$

The relations between frequency and reactance for the capacitor and inductor are opposite – inversely proportional for the capacitor and directly proportional for the inductor. We will try to understand qualitatively why this is so.

A capacitor stores charge. Imagine an RC circuit such as shown in Figure 1. If the voltage source switches rapidly between positive and negative, the capacitor may never have time to reach its maximum charge. So in the limit of high frequency, the capacitor presents very little "resistance" to current flow. Conversely, in the limit of low frequency, the capacitor WILL have time to charge fully. When it does so, the charge that has previously accumulated on the plates opposes the function generator. Therefore the reactance is large at low frequency.

1→For the capacitor in Circuit 1, calculate the reactance for all five of the following frequencies: 10 Hz, 100 Hz, 1,000 Hz, 10,000 Hz, and 100,000 Hz.

2→Using elementary SI units, determine the units of capacitive reactance and show that they are equivalent to ohms.
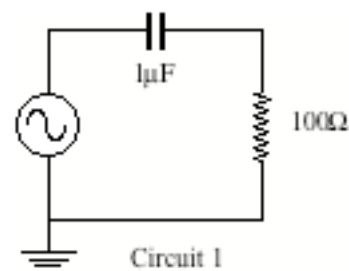
Circuit 1

The impedance, Z of an RC series circuit, represents the combined effects of both the capacitor and the resistor and is given by

$$Z_{RC} = \sqrt{R^2 + (X_c)^2}$$

3→Predict the minimum impedance for Circuit 1. Explain your reasoning.

An inductor resists <u>changes</u> in current. Consider an RL circuit such as shown in Circuit 2. An inductor is a coil which obeys Lenz' Law. It creates a back emf that opposes any change in current. If the driving frequency is large, the inductor responds with a large back emf. Thus the "resistance" is large for high frequencies. Conversely, in the limit of low frequency, the function generator drives a slow change in current, and the inductor responds with small back emf. Therefore the reactance is small at low frequencies.

4→For the inductor in Circuit 2, calculate the reactance for all five of the following frequencies: 10 Hz, 100 Hz, 1,000 Hz, 10,000 Hz, and 100,000 Hz.

44mH

100Ω

Circuit 2

5→Using elementary SI units determine the units of inductive reactance and show that they are equivalent to ohms.
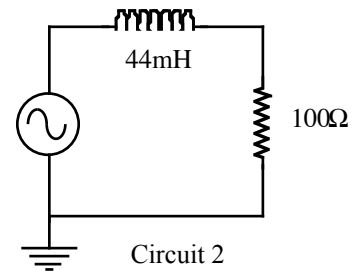
The impedance, Z of an RL series circuit represents the combined effects of both the inductor and the resistor and is given by

$$Z_{RL} = \sqrt{R^2 + (X_L)^2}$$

6→Predict the minimum impedance for Circuit 2. Explain your reasoning.

When an inductor and capacitor are placed in series in the same circuit, the impedance is large at both high and low frequencies. At some intermediate frequency, the impedance will be minimum. This is the resonant frequency of the circuit:
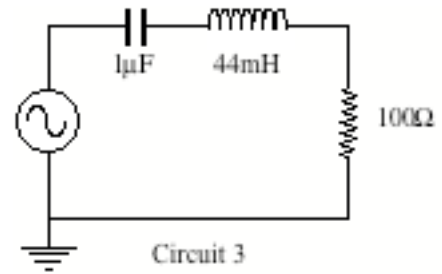
$$f_0 = \frac{1}{2\pi\sqrt{LC}}.$$

The impedance, Z of an RLC series circuit represents the combined effects of the capacitor, the inductor, and the resistor and is given by

$$Z_{RLC} = \sqrt{R^2 + (X_L - X_c)^2}.$$

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7→ Predict the minimum impedance for Circuit 3. Explain your reasoning.

8→ Predict the resonant frequency for Circuit 3. Explain your reasoning.

Circuit 3

9→ Calculate the impedance, Z, for circuit 3 at the following five frequencies: 10 Hz, 100 Hz, 1,000 Hz, 10,000 Hz and 100,000 Hz. Next calculate the peak to peak current at these five frequencies, when the applied voltage is 1 volt peak to peak. Remember, for a series circuit $I_{pp} = \frac{V_{applied\ pp}}{Z}$.

10 → Using the numbers from your calculations in Question 9 above, draw a practice plot of the current in circuit 3 versus the frequency. See the third paragraph in the Procedure section below for information on how to construct this plot.

Procedure   [component values will differ from those above]

Part I: RC Circuit (High-Pass Filter)

Set up Circuit 1. Set the function generator output to 3V peak-to-peak amplitude. Monitor the voltage across the resistor (R =692Ω) using channel one and the top half of the oscilloscope screen. Monitor the function generator output directly using channel two and the bottom half of the oscilloscope screen. The output from the function generator will change slightly when you change the frequency. This is a minor defect in the generator. As you change the frequency, tweak the amplitude to keep it constant at $3V_{pp}$.

Measure the peak to peak voltage across the resistor as a function of frequency. Then calculate the magnitude of the peak-to-peak current flowing through the resistor in the circuit, that is $I_{pp} = \frac{V_{R\ pp}}{R}$. Repeat this measurement for frequencies that range from 10 Hz to 100,000 Hz taking a minimum of 12 data points. As you take your data, plot the peak to peak current as a function of frequency. Plotting as you go helps you to determine how to space measurements for an accurate graph. For instance more data points may be necessary when a curve is changing shape rapidly.

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Since the frequency range of interest is so large, use the log-log graph paper attached at the end this handout, for your graph. There is another reason to use log-log paper: the predicted power law behavior of the current vs frequency. Plot peak-to-peak current on the vertical log axis and frequency on the horizontal log axis. Set up the axes with appropriate units, labels and ranges. Remember that graphs should have a title. We will consciously neglect error in these data, as time is limited and it isn't necessary to track uncertainty in every single measurement (for this particular instructional exercise).

## Part II: RL Circuit (Low-Pass Filter)
Repeat the procedure for Circuit 2. Use a multi-meter (there are several available in the lab) to determine and measure all sources of resistance in your circuit. For ease of comparison, plot the data for this circuit on the same sheet of graph paper used for Part I

Part III: RLC Circuit
Repeat the procedure for Circuit 3. For ease of comparison, plot the data for this circuit on the same sheet of graph paper used for Parts I and II.

Part IV: RLC Circuit #2
You may have noticed that your RLC circuit in the previous exercise had a wide maximum in its current (or voltage) vs frequency plot, i.e. the resonance was not very narrow and thus the circuit was not very "selective" in frequency. This is because of the dissipation of power in the resistor. So let's make a resonant circuit that is more selective. Using the supplied 150μH ferrite core inductor and 20-400pF variable capacitor (C_t in figure below), construct a LC parallel circuit. What is the expected impedance across this parallel LC circuit vs frequency? Again, try to measure all sources of resistance. Next, inductively couple some oscillator power into this circuit via 2-3 turns of wire wound around the inductor. Hook this coupling coil in series with a 50 ohm resistor (so as not to load down the oscillator output amplifier) and apply a small fraction of a volt from your oscillator at a frequency near where you calculate the resonance of your LC circuit will be for an intermediate setting of the variable capacitor (say 250pF). With your scope switched to high input impedance, measure the voltage across your LC circuit as you "tune" your variable capacitor. Observe the resonance. Do the reverse too: set your oscillator to a frequency near your resonance, and then change the oscillator frequency measuring the peak-to-peal voltage as you go, mapping out this resonance. Some of the elective experiments use this kind of circuit. Plot this curve and fit it with an appropriate function (you will do this in some of the elective experiments).
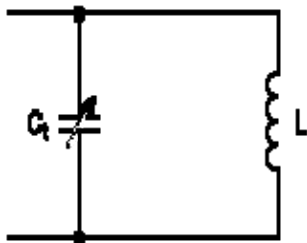
Appendix. The Oscilloscope
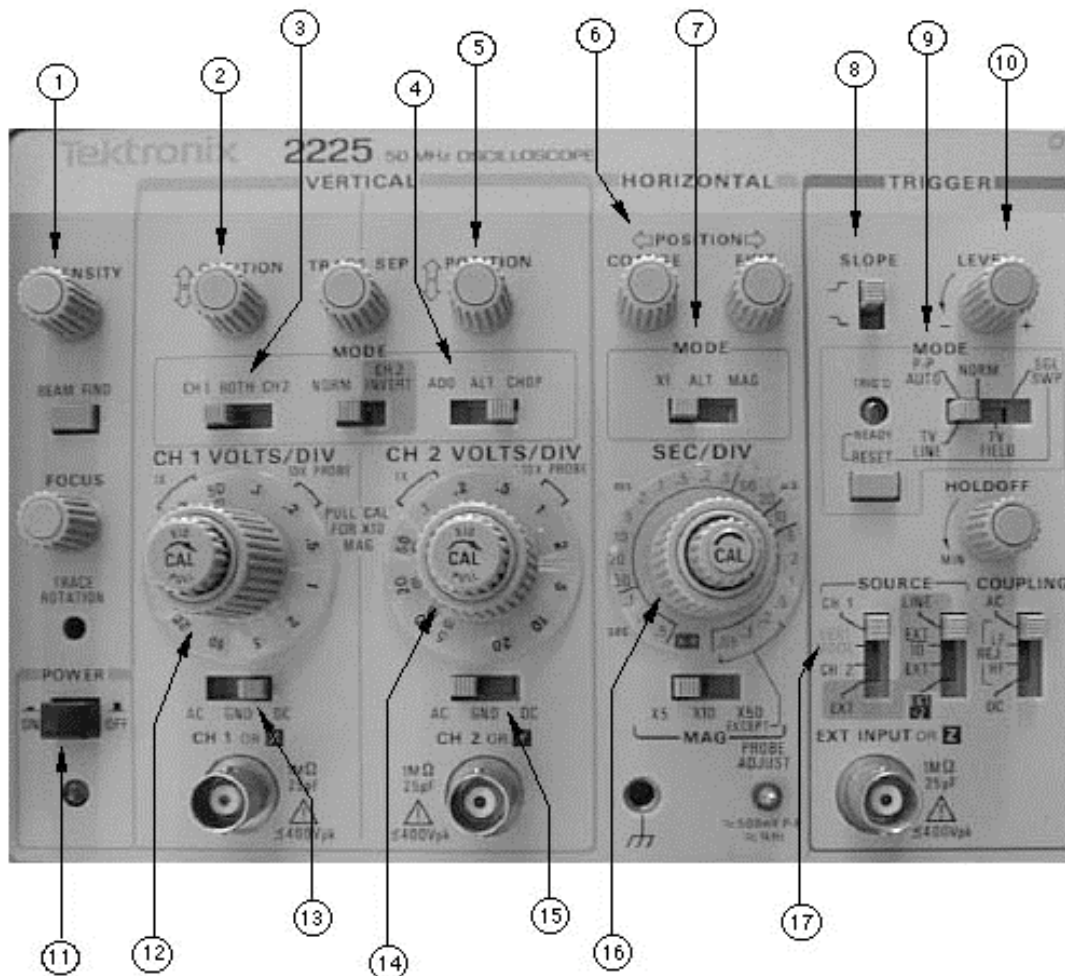
The oscilloscope (scope) is an instrument that displays a "real time graph" of an electrical signal. In most applications, the scope shows how electrical signals vary with time. The vertical axis of the graph represents voltage, while the horizontal axis represents time. The display or graph that you see on the scope screen is drawn by a beam of electrons. This beam appears as a dot when there is no vertical or horizontal signal. The oscilloscope front panel is divided into three sections: the vertical amplifier controls, horizontal sweep controls, and trigger controls.

→ Note: The various scope controls in the picture above are numbered for ease of location. The following sections describe the operation and functions of these controls that are referenced with the appropriate number in bold face.

Vertical Section

This scope has two vertical amplifiers: channel 1 and channel 2 (CH 1, CH 2). Each channel has a calibrated *voltage sensitivity* switch **12 and 14**, which set the voltage scale VOLTS/DIV displayed on the screen. The *coupling switches* **13 and 15** *select* which type of signals can be displayed, DC displays all voltages, AC only alternating voltages, and GND where no voltage is displayed. The *vertical input mode* **3** selects which channel or combination of channels is displayed. CH 1 displays channel 1, CH 2 displays channel 2. BOTH ALT or BOTH CHOP **3 and 4,** display two channels simultaneously, while BOTH ADD **3 and 4**, display the sum of Channel 1 and 2. The *vertical position* knobs **2 and 5** move the display up or down on the screen. For accurate voltage measurements the small knobs marked CAL in the center of the *voltage sensitivity* switches **12 and 14** must be turned completely clockwise.

Horizontal Section

The *horizontal sweep* sec/DIV **16** controls the speed of the electron beam as it "sweeps" across the screen. The sweep speed can be varied between 5 sec/div to .05 µs/div. The *horizontal position* knob **6** allows you to move the display from side to side. The *horizontal mode switch* **7** should be set at X1. For accurate time measurements, the small knob marked CAL in the center of the *horizontal sweep* sec/DIV **16** must be turned completely clockwise.

Triggering Section

The key to a scope's operation is its ability to trigger on a particular point of a waveform in order to "freeze" a rapidly changing signal into a stationary display. Each time the horizontal sweep repeats the trigger must catch the input signal at the same point in the waveform. Without this timing, the display would be a mess. The trigger tells the scope "when to take the picture". Two useful ways to trigger a scope are the normal and auto modes. In *trigger mode* NORM **9** you select, a LEVEL **10** (a particular voltage) and a SLOPE **8** + or - (voltage increasing or decreasing), to trigger on. When the input signal reaches that set point, the trigger circuits start the sweep. In practice you adjust the LEVEL and SLOPE for the most stable display. You select which input signal you want to trigger on with the *trigger source* switch **17**, CH 1 or CH 2. In the *trigger mode* AUTO **9** the scope will "free run" even when no signal is present. This feature is useful when you are looking for a signal with an unknown voltage and shape. Once you find the signal, you may have to switch to *trigger mode* NORM **9** to stabilize the signal.