

Introduction to Analog Electronics

Preparation: Before coming to lab, read this guide and *Electronics* under Additional Resources for Week1 as well as the tutorial "RLC circuits." Then answer the numbered questions in bold face that appear throughout this lab guide. Answers to these pre-lab questions should be in your lab book at the beginning of 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 oscilloscopes on the 123 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 μ H 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 \sim 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

$$X_C = \frac{1}{2\pi fC}.$$

And the reactance of an inductor is

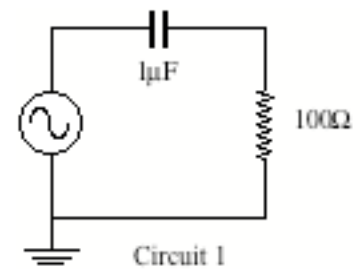
$$X_L = 2\pi fL.$$

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.



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

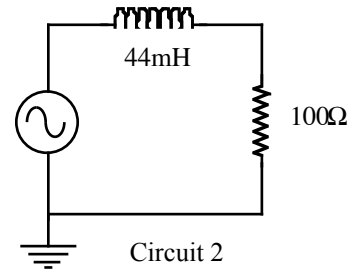
$$Z_{RC} = \sqrt{R^2 + (X_C)^2}$$

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

An inductor resists changes 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.

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:

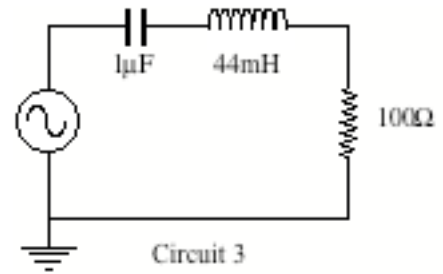
$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

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

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

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

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



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 $I_{pp} = \frac{V_{\text{applied pp}}}{Z}$.

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)

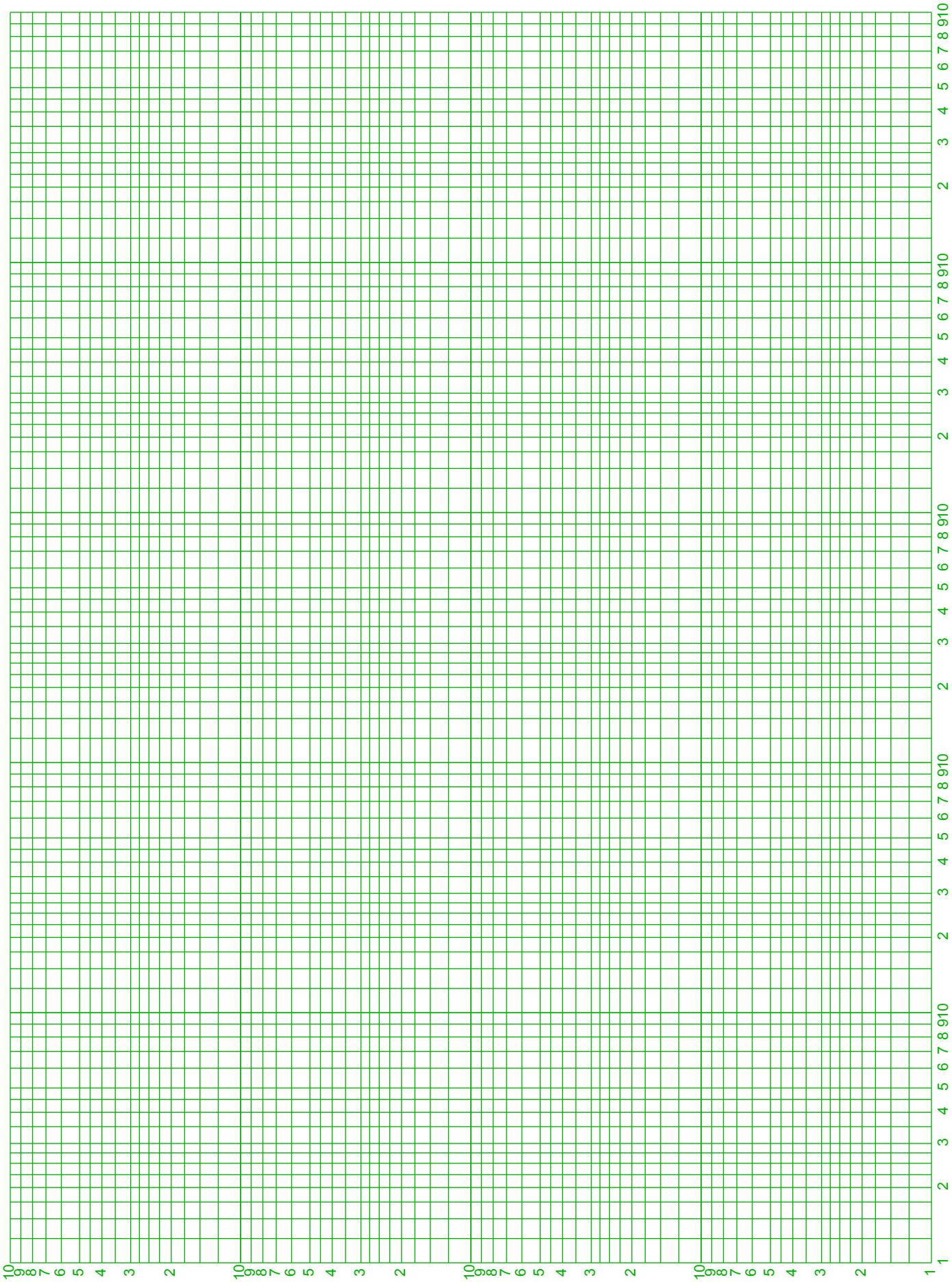
Set up Circuit 1. Set the function generator output to 3V peak-to-peak amplitude. Monitor the voltage across the resistor ($R = 692\Omega$) using channel one and the top half of the oscilloscope screen. Monitor the function generator output directly using channel two and the bottom half of the oscilloscope 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.

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: RC Circuit (Low-Pass Filter)

Repeat the procedure but with the resistor and capacitor switched. Before doing the measurements, do the math for the complex impedances for your filter and then as before take the real part to get your output voltage amplitude vs frequency. For ease of comparison, plot the data for this circuit on the same sheet of graph paper used for Part I



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