Names ______________________________

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AC Circuits

This lab deals with circuits involving resistors, capacitors and inductors in which the currents and voltages vary sinusoidally in time.

Equipment

1 function generator (PC Scope software)
1 digital multimeter and leads
1 decade resistance box
1 capacitor (nominally 1 μF)
1 inductor (nominally 10 mH)
1 mini-jack to banana plug (black, red, blue) cable, 2 alligator clips

Introduction

If the current through a passive component is given by

$$i(t) = I\sin(\omega t) = I\sin(2\pi f t)\,. \tag{1}$$

then the voltage across the component also varies sinusoidally, but with a phase that depends on the component. For a resistor the voltage is in phase with the current. For a capacitor the voltage lags the current by 90^o, and for an inductor the voltage leads the current by 90^o. The peak (or rms) current-voltage relationships for a resistor, capacitor and inductor are

$$V_R = IR \tag{2}$$

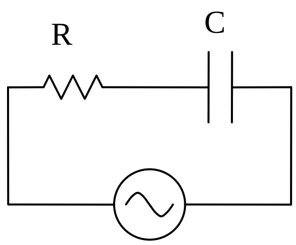
$$V_C = IX_C = I/(\omega C) \tag{3}$$

$$V_L = IX_L = I\omega L \tag{4}$$

<u>Series RC Circuit</u>

In a series *RC* circuit, since the currents are the same then the voltages across *R* and *C* are 90^o out of phase. Consequently, the total voltage across the combination is

$$V = I\sqrt{R^2 + X_C{}^2} \tag{5}$$



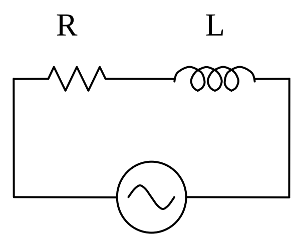
$v(t) = V\sin(\omega t + \varphi)$

<u>Figure 1</u>

Series RL Circuit

In a series *RL* circuit, the voltages across *R* and *L* will also be 90° out of phase. Thus,

$$V = I\sqrt{R^2 + X_L^{\;2}} \qquad (6)$$



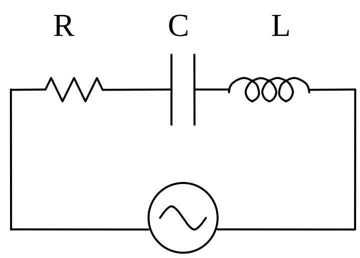
$v(t) = V\,sin(\omega\, t+\varphi)$

Figure 2

Series RLC Circuit

In a series *RLC* circuit, since the voltage across *L* leads the current by 90° and the voltage across *C* lags the current by 90°, then the voltages across *L* and *C* are 180° out of phase. Consequently, we have

$$V = I\sqrt{R^2 + \left(X_L - X_C\right)^2}\ . \qquad (7)$$



$v(t) = V\,sin(\omega\, t+\varphi)$

Figure 3

We can write this as $V = I\,Z$, where $V = Z = \sqrt{R^2 + \left(X_L - X_C\right)^2}$ is the circuit impedance. In the series *RLC* circuit, the current will be a maximum when the impedance is a minimum, that is, when $X_L = X_C$, or

$$f = f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad (8)$$

Preliminary Questions

1. In a series *RC* circuit, V_R and V_C are measured as a function of frequency. Do you expect V_R and V_C to increase, decrease, or remain constant as you change *f*? Show your predictions by making a sketch of V_R and V_C versus *f*.

2. In a series *RL* circuit the rms voltage across *R* is 30 V and the rms voltage across *L* is 40 V. What is the rms value of the voltage across the *RL* combination?

3. In a series *RLC* circuit, the rms voltage across *L* is 40 V and the rms voltage across C is 60 V. What is the rms voltage across the *LC* combination?

Procedure

In this experiment, you will use the function generator feature of the PC soundcard *Oszilloscope* program for your voltage source and the handheld multimeter to measure the voltages. (You will not use the PC oscilloscope.) The *Oszilloscope* program can be accessed from the 'Scope' icon on the desktop. Use the red and black leads of the cable for the function generator output.

<u>Series RC Circuit</u>

Wire the series *RC* circuit as shown in Fig. 1. Use the decade resistance box and set R = 50 Ω. (Note: Measure the resistance to ensure that R is approximately the set value. If it is way off, then this particular setting is damaged. Then pick another setting (e.g., 40 Ω or 60 Ω).) Turn Channel 1 of the 'scope' function generator on, set it to 'sine', and set the amplitude to '1'. (Note: The actual function generator output voltage will depend on the load.) Now use the multimeter to measure V_R, V_C and V (function generator voltage) as a function of frequency over the range from 100 Hz to 8000 Hz. Use steps of 100, 1000, 2000, … , 8000 Hz.

Enter your data into Excel. In a separate column calculate $\sqrt{V_R{}^2 + V_C{}^2}$. Now on a single graph, plot V_R, V_C, V, and $\sqrt{V_R{}^2 + V_C{}^2}$ as a function of f.

<u>Analysis:</u>

1. Are your measurements in qualitative agreement with your answer to Preliminary Question 1? Explain.

2. How does your source voltage, V, compare with $\sqrt{V_R{}^2 + V_C{}^2}$? Why don't the voltages add as $V = V_R + V_C$?

3. Note the frequency at which $V_R = V_C$. Use this value of f and your known value of R to calculate C.

<u>Series RLC Circuit</u>

Now add the inductor in series with the above circuit to form a series *RLC* circuit. Measure the voltage across the resistor as a function of frequency from 100 to 4000 Hz. Use steps of 100, 500, 1000, …, 4000 Hz. Note the approximate frequency where V_R reaches its maximum value. Now add a few additional measurements at frequencies near this value to better define your resonance.

Analysis:

1. Make a graph of V_R versus f and determine the resonance frequency, f_0. Use Eq. (8) and your previously determined values of R and C to calculate L.

2. Set your frequency to the resonance value. Now measure V_L, V_C, and V_{LC} , the voltage across the LC combination. Ideally, at resonance the voltages across L and C are 180^0 out of phase and exactly cancel so that $V_{LC} = 0$. Presumably, this is not what you observe. The reason is because the inductor has a resistance R_L that is effectively in series with L. So, at resonance you would expect that $V_{LC} = IR_L$. Use the multimeter (resistance setting) to measure R_L. Measure the source voltage V and calculate the current using $I = V/(R+R_L)$. Then calculate IR_L and compare with your measured value of V_{LC}.

3. The 'quality factor', Q, of the resonant circuit is defined as

$$Q = \frac{f_0}{\Delta f}, \qquad (9)$$

where Δf is the width of the resonance curve measured between points where the power dissipation is ½ the value at resonance. Since $P = V_R^2/R$, the half-power points correspond to the points where $V_R = V_R(max)/\sqrt{2}$.

It can be shown that Q can be calculated using the expression

$$Q = \frac{2\pi\, f_0}{R} \qquad (10)$$

Measure Q using Eq. (9) and compare with your calculated Q using Eq. (10). In Eq. (10) R should be the total resistance of the circuit (decade box plus coil resistance).

Turn in your Excel graphs and answers to all questions.