

AC CIRCUIT EXPERIMENT

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 0.1 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

$$i(t) = I \sin(\omega t) = I \sin(2\pi f t) \quad (1)$$

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° , and for an inductor the voltage leads the current by 90° . The peak (or *rms*) current-voltage relationships for a resistor, capacitor and inductor are

$$V_R = IR \quad (2)$$

$$V_C = IX_C = I / (\omega C) \quad (3)$$

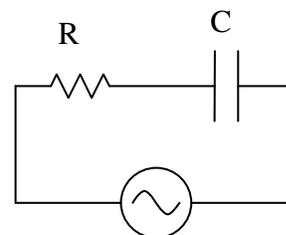
$$V_L = IX_L = I\omega L \quad (4)$$

Series RC Circuit

In a series *RC* circuit, since the currents are the same then the voltages across *R* and *C* are 90° out of phase.

Consequently, the total voltage across the combination is

$$V = I\sqrt{R^2 + X_C^2} \quad (5)$$



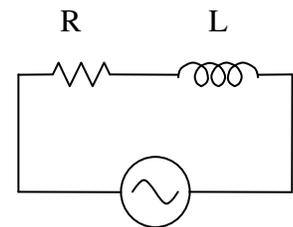
$$v(t) = V \sin(\omega t + \varphi)$$

Figure 1

Series RL Circuit

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

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



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

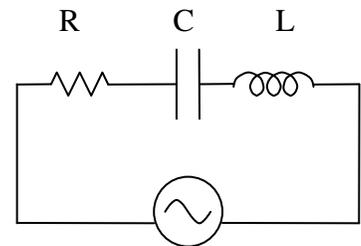
Figure 2

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

$$V = I\sqrt{R^2 + (X_L - X_C)^2} \quad (7)$$

We can write this as $V = IZ$, where $Z = \sqrt{R^2 + (X_L - X_C)^2}$ 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



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

Figure 3

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

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?

Procedure

In this experiment, you will use the function generator feature of the PC *Soundcard Oscilloscope* program for your voltage source and the handheld multimeter to measure the voltages. (You will not use the PC oscilloscope.) The *Oscilloscope* 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 and make sure the volume of the PC soundcard is not set on *mute*.

Series RC Circuit

Wire the series *RC* circuit as shown in Fig. 1. Use the decade resistance box and set $R = 500 \Omega$. (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., 400Ω or 600Ω .) 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, 500, 1000, 1500, 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 .

Analysis:

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 .

$$f = \underline{\hspace{2cm}} \quad C = \underline{\hspace{2cm}}$$

Series RLC Circuit

Now add the inductor in series with the above circuit to form a series *RLC* circuit. Change the resistance setting from 500Ω to 50Ω . (Check the value of the resistance with the multimeter, if 50Ω is not working try 40Ω or 60Ω .) Measure the voltage across the resistor as a function of frequency from 100 to 8000 Hz. Use steps of 100, 500, 1000, ..., 8000 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 .

$$f_0 = \underline{\hspace{2cm}} \quad L = \underline{\hspace{2cm}}$$

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

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

where Δf is the width of the resonance curve measured between points where the power dissipation is $\frac{1}{2}$ the value at resonance. Since $P = V_R^2/R$, the half-power points correspond to the points where $V_R = V_R(\text{max})/\sqrt{2}$.

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

$$Q = \frac{2\pi f_0 L}{R} \quad (10)$$

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).

$$Q_{\text{Measured}} = \underline{\hspace{2cm}} \quad Q_{\text{Calculated}} = \underline{\hspace{2cm}} \quad \% \text{difference} = \underline{\hspace{2cm}}$$

3. 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° 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} .

Turn in your Excel graphs; Exit the Scope program and answers to all questions.