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Physics 212-8

Tuning and LRC Circuits

NAME: ______________________________ ☐

STUDENT ID: ______________________________ ☐

LAB PARTNER(S): ______________________________ ☐

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Check the box next to the name of the person to whose report your group's data will be attached.

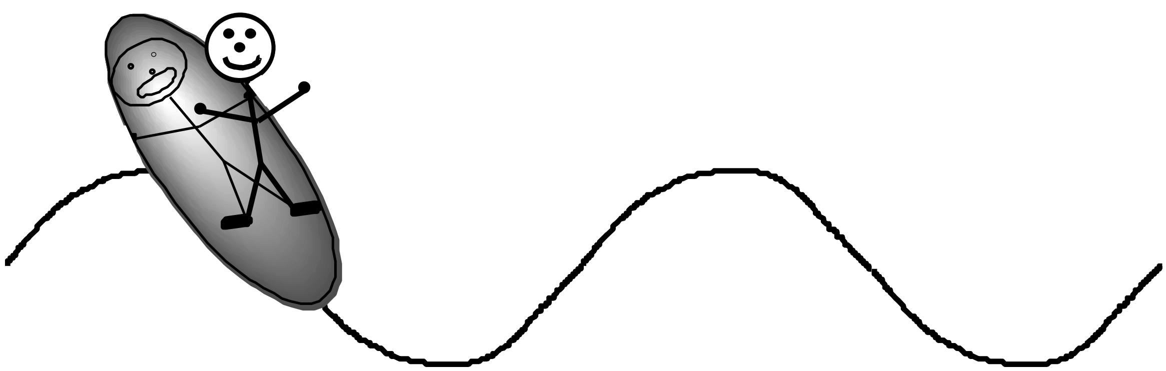
LAB SECTION: ________________________

INSTRUCTOR: ________________________

DATE: ________________________

TABLE: ________________________

(YOU WILL BE TAKEN 3 POINTS IF TABLE IS VACANT.)



Written by Beda, Dick, Hearn, Hertzog, Makins & Weissman, modified by Xia Huanxin for ZJUI

Physics Lab 212-8

Equipment List

Oscilloscope with two banana jack adapters

Wires for connections

Digital Multimeter (DMM)

function generator

Capacitor, 1.5 nF mounted on dual banana plug

Inductor, 500 mH mounted in an aluminum box

Resistor, 470Ω mounted on dual banana plug

Circuit board

Inductor mounted on wood board

Variable capacitor

5 m long wire with banana plugs on both ends

Diode mounted on dual banana plug

Earphone for listening to audio signal in the radio circuit

Radio frequency generator and audio frequency generator setup at the front of the room
with attached antenna wire extending to the back of the room

Differential amplifier

Two DC power supplies per room for the differential amplifiers

Physics Lab 212-8

Tuning and LRC Circuits

Investigation 1: The *LRC* Series Circuit

Preview

- Tune a function generator to the resonant frequency of an *LRC* circuit.
- Find the quality factor of the *LRC* circuit
- Change *R* and find the new quality factor of the *LRC* circuit

Activity 1 Resonance in an *LRC* Circuit

In an *LRC* circuit there exists a special frequency, known as the *resonant frequency*, where the impedance reaches a minimum and the current reaches a maximum. Impedance is minimized when X_C and X_L cancel in the expression for *Z*. The phenomenon of resonance in AC circuits is what makes tuning a radio or television possible; when you "tune in" a station, you are actually tuning an *LRC* circuit inside your radio or television to the station's transmitting frequency.

In an *LRC* circuit, the resonance angular frequency ω_o is given by

$$\omega_o = \frac{1}{\sqrt{LC}} \qquad \text{(Eq. 1)}$$

where *L* is the inductance and *C* is the capacitance. Notice that the resonant frequency is independent of the resistance in the series circuit.

Theory Calculation

Calculate the angular resonance frequency ω_o and the corresponding frequency f_o of a series *LRC* circuit with $C = 1.5$ nF, and $L = 500$ mH.

$\omega_o =$ ________ [radians/second]

$f_o =$ ________ [Hz]

1. Component measurements.
   - Set your DMM to measure resistance. Measure the resistance of R_1 (the 470Ω resistor) and the inductor's resistance R_L. Add them to find the total resistance *R* and record all three below.

$R_1 =$ ________ [Ω]

$R_L =$ ________ [Ω]

$R =$ ________ [Ω]

2. Set up the scope and circuit.
   - Make sure the function generator is OFF. Set up the series *LRC* circuit shown in Figure 1 and connect it to the function generator. Be sure to connect the circuit to the **GND** and **LOΩ** terminals of the function generator and make sure that the function generator's **GND** lead is connected to the capacitor, not the resistor.
   - Connect the inputs and outputs of the differential amplifier to the circuit and scope as shown in Figure 1. This will give you the voltage across the resistor which gives you a measure of the current in the circuit.
   - Set the DMM to read AC voltage across the capacitor.

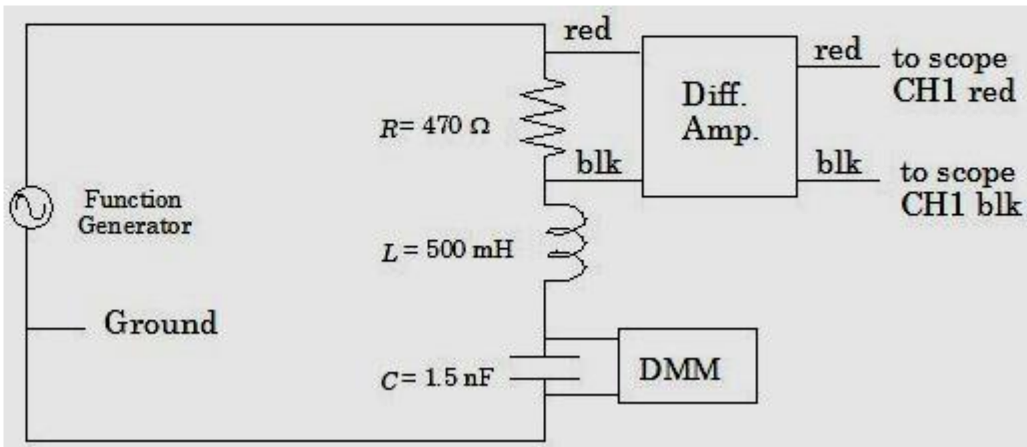


Figure 1. The series *LRC* circuit

3. Adjust and set controls.
   - Adjust the amplitude of the function generator to a little less than half of the maximum setting and then turn it on. Adjust the frequency to about 5000 Hz.
   - Turn the oscilloscope on and press the **AUTOSET** button to have the scope set its internal parameters to reasonable values.

4. Find the resonance frequency.
   - Begin a coarse tuning for resonance by first setting your signal generator to 5000 Hz, then slowly sweeping through the frequency range to nearly 7000 Hz while watching your oscilloscope. You may have to press **AUTOSET** several times to keep the full signal displayed on the scope. You should notice a gradual rise that reaches a maximum at some frequency, and then a gradual fall in the amplitude of the oscilloscope trace.
   - Tune the frequency of the function generator to exactly the resonance frequency of the circuit by adjusting the frequency slowly and using the scope to find the maximum (peak) RMS voltage across the resistor. Note that the RMS voltage of the signal can be read on the screen of the scope by selecting the **MEASURE** Menu and selecting **display all 'on'**.

- Record the resonant frequency (from the display of the function generator) below.

Resonant frequency $f_o =$ ________ [Hz]

- Leave this circuit connected for the next activity.

Q1 Compare your experimental value for the resonant frequency f_o with your calculation. Calculate a percentage difference. What could be a source for the difference?

____
____
____
____
____

Activity 2 The Quality of an LRC Circuit

As you can see from Eq. 1, a wide range of values for L and C can be used to establish a particular resonant frequency. The resistance R does not enter in the determination of ω_o. However, the way in which the circuit reacts to frequencies *near* the resonant frequency is greatly affected by the resistance.

For a sharp resonance, defined as one with a narrow width around the resonant frequency, a circuit is said to have a high Q ("quality factor").

Recall from your Prelab that the Q factor is defined as

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{\sqrt{X_{L_0} X_{C_0}}}{R} \qquad \text{(Eq.2)}$$

where X_{L_o} and X_{C_o} denote the inductive and capacitive reactance at resonance. Note that since X_{L_o} and X_{C_o} are equal in magnitude at resonance, Q is a ratio of the magnitude of either the inductive reactance or the capacitive reactance of the circuit to the resistance of the circuit.

Using the expression $\omega_0 = 1/\sqrt{LC}$ one can rewrite the middle form of Eq. 2 in a variety of forms, such as

$$Q = \frac{X_{L_O}}{R} = \frac{\omega_O L}{R} = \frac{X_{C_O}}{R} = \frac{1}{R\omega_O C} \qquad \text{(Eq. 3)}$$

Also recall that for Q > 3 that Q can be approximated by the following;

$$Q = \frac{\omega_o}{\Delta\omega} = \frac{f_o}{\Delta f} \qquad \text{(Eq. 4)}$$

The quantity Δf is defined as follows: At frequencies $\pm\Delta f/2$ from the resonant frequency, the average power consumed by the circuit drops by a factor of 2 compared to the power at resonance. The quantity Δf is known as the FWHM (full width at half maximum*)*. You can determine the FWHM from a graph of power versus frequency for a given circuit, and thus measure *Q* from such a plot. See Figure 2. You can also determine the FWHM by determining the voltage at resonance and then finding the frequencies above and below resonance where the voltage decreases by a factor of $\sqrt{2}$.

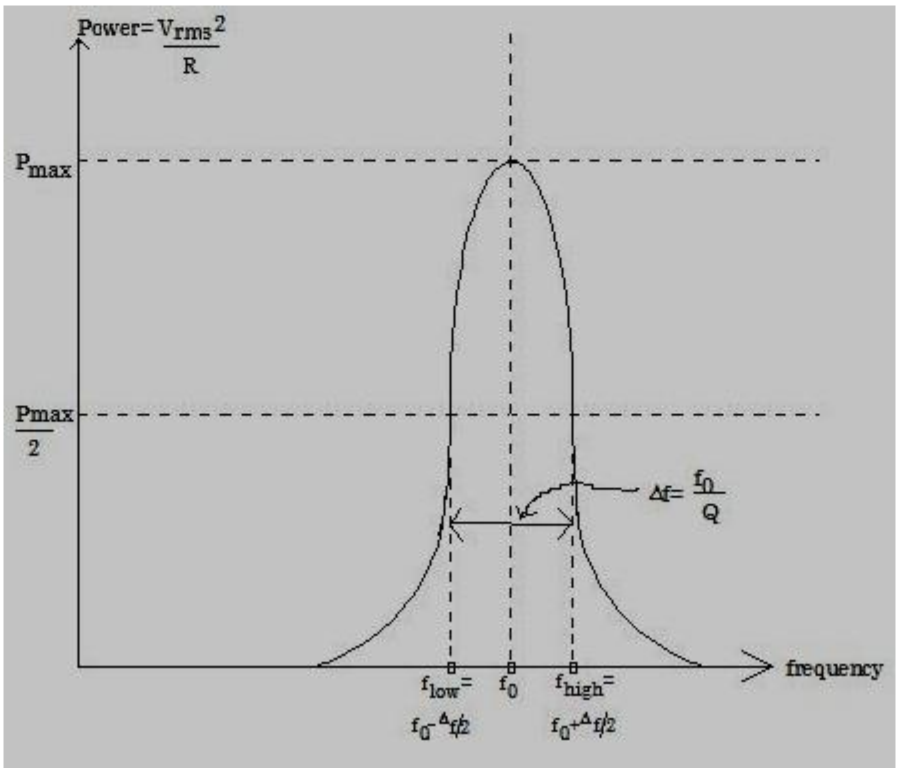
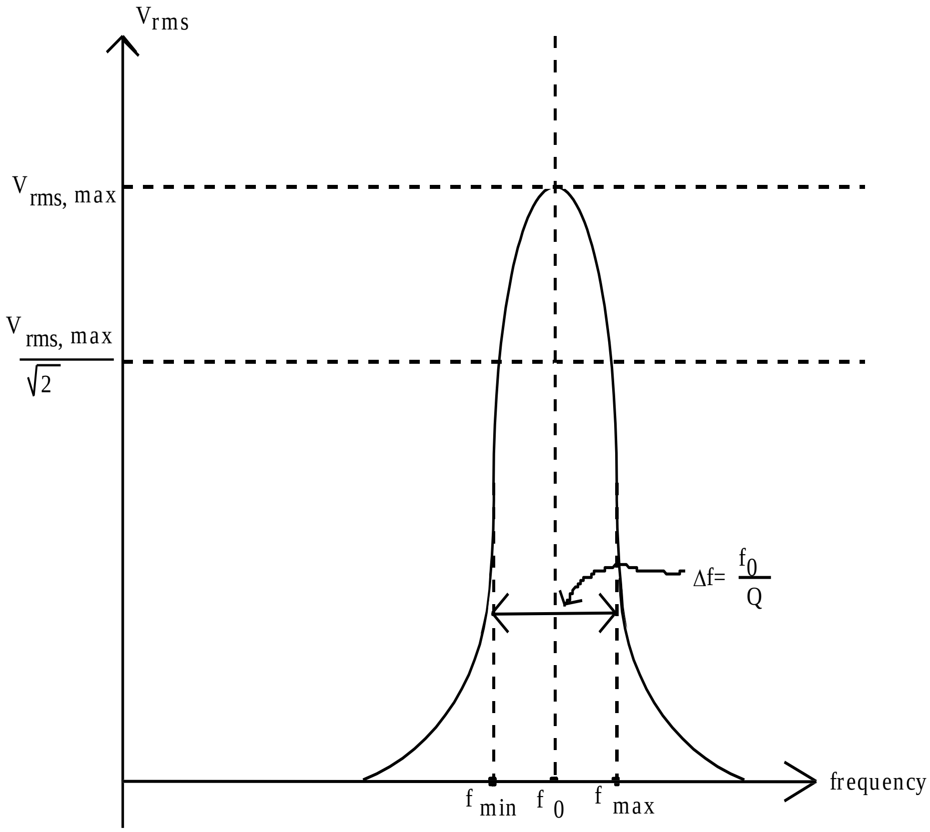


Figure 2. Power vs. frequency in the RLC circuit



V_{rms}
$V_{rms,\ max}$
$\frac{V_{rms,\ max}}{\sqrt{2}}$
$\Delta f = \frac{f_0}{Q}$
frequency
f_{min}
f_0
f_{max}

Calculation

Using Eq. 3, compute the *Q* factor for your circuit. Note that because the value of capacitance can be off by up to 25%, use a formula for Q that does not depend on C. Use this computed *Q* and Eq.4 to determine the frequencies f_{low} and f_{high} plus the FWHM. Remember R is the total resistance of the circuit.

Q = ________

FWHM = Δf = ________ [Hz]

$f_{high} = f_o + \Delta f/2$ = ________ [Hz]

$f_{low} = f_o - \Delta f/2$ = ________ [Hz]

Determine *Q* and FWHM using Eq. 4 and measured values of f_{high} and f_{low}.

1. Measure the quality of the circuit.

- Make sure the frequency is still at the resonant frequency you found in Activity 1.
- Using the **amplitude** knob of the function generator, adjust the RMS voltage across the resistor to 2.50 V.
- Lower the frequency until the RMS voltage across the resistor equals 1.77 V. Record this frequency below as f_{low} .
- Raise the frequency above the resonance until the RMS voltage again equals 1.77 V. Record this frequency below as f_{high}.
- Compute the values for FWHM and *Q* and enter them below.

f_{low} = ________ [Hz]

f_{high} = ________ [Hz]

FWHM $\equiv \Delta$f = ________ [Hz]

$Q \approx \dfrac{f_O}{\Delta f}$ = ________

Q2 How does this measurement of Q compare to your calculation using Eq.3 in the calculation box above? Give absolute and percent comparison.

____

____

Q3 What is the reason that you set the voltage to 2.50 V at resonance and then sought the frequencies where the voltage fell to 1.77 V to find f_{low} and f_{high}? (Hint: Consider power in the definition of Δf. What is power proportional to?)

____

____

Recall the power versus frequency graph of an LRC circuit from the Prelab and consider Equations 3 and 4 above.

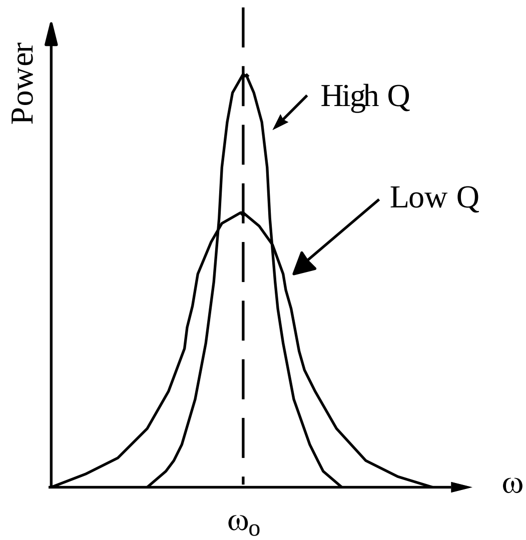


Figure 3. Series *LRC* circuit response

Figure 3 compares the response for a low and high Q circuit. Later in the lab we will construct a radio receiver, basically an LRC oscillator.

Q4 For the best performance, do you want a high or a low Q? Which will give a stronger signal? Which will better discriminate against "adjacent" stations, i.e., at a nearby frequency? For a higher Q, do you want a higher or lower resistance?

Activity 3 Exploring the Dynamics of Resonance in an LRC Circuit

Until now, you have been exploring the power delivered to the LRC circuit at resonance. Where are the large oscillations you expect to find in a system that is driven at its resonant frequency? Remember from your mechanics lab that a spring-mass system driven at the system's resonant frequency oscillated with an amplitude that was much larger than that of the driver. There is a parallel for this in the series LRC circuit. The voltage across each of the reactive circuit elements can become very large compared to the driving voltage of the function generator. How large? It depends on the Q of the circuit. At resonance, Q is a ratio of the magnitude of either the inductive reactance of the circuit or (equally at resonance) the magnitude of the capacitive reactance of the circuit to the resistance of the circuit, i.e., ***Q* is an amplification factor** for the reactive component of the voltage across the capacitor or the inductor in a series LRC circuit when it is driven at its resonant frequency. This assumes that all the inductance in the circuit is in the inductor and all the capacitance in the circuit is in the capacitor.

Theory Calculation

If you drive the circuit in your last activity with the function generator output at 2V RMS, what should the maximum RMS voltage across the capacitor be? Use your measured Q (as an amplification factor) to make your calculation.

Voltage across C = __________________V

1. Check your calculation.
   - Reset the frequency of the drive to f_o, i.e., back on resonance.
   - Use the DMM to read the AC voltage across the capacitor: V_C = _________
   - Next move the DMM to read the voltage from the function generator: V_{fg} = ______

Q5 Compare the ratio of V_C / V_{fg} to the Q you calculated for this circuit: Give a percentage difference.

____

How can the voltage across the capacitor be so high at resonance compared to the driving voltage (V_{fg}) of the function generator without violating the loop law ($V_{fg} - V_R - V_L - V_C = 0$)?

To help answer this, move the red lead on the DMM to above the inductor, and the black lead to below the capacitor (so that you now read the combined AC voltage across both the inductor and the capacitor).

Q6 What AC voltage did you read? What can you conclude about V_C and V_L?

____

____

CLEAN UP CHECKLIST

☐ Turn off the oscilloscope.

☐ Remove your components from the circuit board so that it is in the same condition you originally found it.

☐ Staple everything together, make sure you have answered all the questions and dome all the activities, make sure the first page is completed with lab partners' names and check boxes, hand in your work.