Lab 6: RLC resonance, Bandwidth and Quality Factor

A. Objectives

- Investigate the resonance phenomena in an RLC circuit. Analyze the Resonant Frequency and Bandwidth of the given circuit and determine the effect of the load resistance on the Quality Factor.

B. Background

B.1. Resonance in a series RLC circuit:

Resonance is a condition in an RLC circuit in which the capacitive and inductive reactances are equal in magnitude, thereby resulting in a purely resistive impedance. Consider the series RLC circuit in Figure B.1.1:

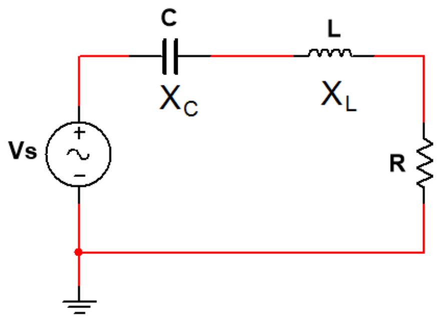

Fig.B.1.1: Series RLC circuit

Here, both X_C and X_L are frequency dependent. However, X_C is inversely proportional to frequency and X_L is directly proportional. That is, as the frequency is increased, X_C decreases and X_L increases. This means there must be a source frequency for which $X_C = X_L$. A circuit operating in that frequency is said to be in resonance condition. At the resonance condition, $X_C = X_L$, which means $\frac{1}{j\omega C} = j\omega L$. This expression can be simplified to obtain the following expression for the resonance frequency, f_0.

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

Now, the impedance in the above circuit can be expressed as: $Z = R + jX_L - jX_C$. Therefore, at resonance condition, the impedance of the circuit is purely resistive, which means that the entire source voltage is across R. At any other operating frequency, the voltage across R will be lower due to the non-zero reactance contributing to the total impedance.

B.2. Bandwidth and Quality Factor

If the series RLC circuit is driven by a variable frequency at a constant voltage, then the magnitude of the voltage, V is proportional to the impedance, Z. Therefore, at resonance the power absorbed by the circuit must be at its maximum value.

If we now reduce or increase the frequency until the average power absorbed by the resistor in the series resonance circuit is half that of its maximum value at resonance, we produce two frequency points called the half-power points or half-power frequencies. These points give us a voltage value that is 70.7% of its maximum resonant value. That is, at the upper and lower cut-off frequencies, say f_1 and f_2, $V = 0.707V_{max}$. The difference between these two points ($f_1 - f_2$) is called the Bandwidth (BW) of the circuit. This bandwidth is also known as the half-power bandwidth.

The “sharpness” of the resonance in a resonant circuit is measured quantitatively by the Quality Factor (Q).The quality factor relates the maximum or peak energy stored in the circuit (the reactance) to the energy dissipated (the resistance) during each cycle of oscillation meaning that it is a ratio of resonant frequency to bandwidth ($Q = \frac{f_0}{BW}$) and the higher the circuit Q, the smaller the bandwidth.

Experiment 1: Resonance in a series RLC circuit

A. Apparatus

Components	Instruments
• Resistors: 1×100Ω (R1), 1×200Ω (R2) • Capacitors: 1×0.1µF • Inductor: 1x560µH	• 1× Bread Board • 1× Function Generator • 1× Digital Storage Oscilloscope(DSO) • Connecting wires and probes

B. Procedure

1. Note down the nominal value of the resistors (R1 and R2), the capacitor (C1) and the inductor (L1) in Table 1.1. Measure the practical value of the resistors using the DMM. Note down the values in Table 1.1.
2. Measure the practical value of the capacitor (C) using an LCR meter and note down the value in Tables 1.1. Do the same for the inductor (L).
3. Construct the circuits shown in Fig.B.1.1 on the bread board. Connect Channel 1 of the oscilloscope across the source VS (positive red port to node 'a' and negative black port to node '0' i.e. ground).
4. To set 3V peak (6V peak to peak) and 1 KHz in the function generator, observe the generated signal on the oscilloscope screen (channel 1) and fine tune the amplitude & frequency of the input signal generated from the function generator to match the nominal values. **Always set the amplitude after setting the frequency because changing the frequency of a non-ideal source might alter the amplitude.**

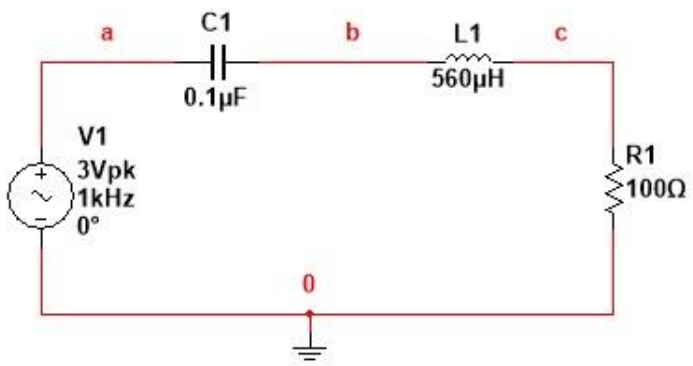

Fig.B.1.1: Series RLC circuit

5. Measure the peak voltage across R1, L1 and C1 and note those down in **Table 1.2**.
6. Set the frequency in the function generator to the next frequency value in **Table 1.2** and adjust the time/division of the oscilloscope so that the wave shape is clearly visible. Readjust the amplitude to 3V peak if necessary.
7. Now, use the same method you used in the previous step 5 to measure the voltages across R1, L1 and C1 for the new input frequency. Note down the values in **Table 1.2**.
8. Repeat step 6 & 7 for all the frequencies in **Table 1.2**.
9. From the data you recorded in Table 1.2, determine the frequency range for which the voltage across the resistor R1 appears to be largest. And connect channel 2 at node 'c'
10. Carefully change the input frequency of the function generator within the range you just found until the maximum voltage value of V_R is obtained. Use the oscilloscope to determine the frequency at which this occurs and note it down in **Table 1.3**. This is the resonant frequency f_0.
11. Now, decrease the source frequency below f_0 until V_R is 70.7% of the maximum value ($0.707V_{Rmax}$). Note down the frequency at which this occurs as the lower cut-off point, f_1.
12. Finally, increase the source frequency above f_0 until V_R is once again 70.7% of the maximum value ($0.707V_{Rmax}$). Note down the frequency at which this occurs as the upper cut-off point, f_2.
13. Change the 100Ω resistor in the circuit with the 200Ω one.
14. Now repeat steps **4 to 12** for the new resistance value. Record your results in **Table 1.4** and **1.5**.

C. Simulation

1. In MULTISIM, construct the circuits in figure B.1.1, and do AC analysis (for both 100Ω and 200Ω resistors) for showing the voltages across the components at different frequencies.
2. Attach the output graphs in your report.

D. Questions

1. Explain why the load voltage in an RLC circuit is maximum at resonance condition.
2. If a 5mH inductor was used instead of the 560µH one, what capacitance value would be required to keep the resonant frequency (f_0) the same as the value you obtained from your experiment?
3. How would the resonant frequency of the circuit given in Figure B.1.1 change if the 100Ω resistor was replaced with a 50Ω one? Explain your answer.
4. Use your experimental results and the graphs you obtained from the simulations to explain the concept of high and low Quality Factor in series RLC circuits.
5. Is it possible to have a resonance condition in a parallel RLC circuit? If so, briefly discuss a possible experimental setup which could be used to investigate resonance in a parallel RLC circuit.
6. Do the practical values of resonant frequency, bandwidth and quality factor you obtained confirm the theoretical values? If any of the percentage differences are above 10%, suggest 3 possible reasons for the discrepancy.

E.1 Data Sheet: Lab 6, Experiment 1

Date:	Points:
Remarks:	

Signature of the Instructor

Student Information

Section:	Group:	Status:

E.1.1 Table 1.1: Component Values

	R$_1$(Ω)	**R**$_2$ (Ω)	**C**$_1$(F)	**L**$_1$(H)
Nominal				
Measured				

E.1.2 Table 1.2: The magnitudes of V_C, V_L and V_R at different frequencies for a high Q circuit

Frequency (f) kHz	Peak Voltage, **V**$_R$(V)	Peak Voltage, **V**$_C$(V)	Peak Voltage, **V**$_L$(V)
1			
10			
20			
30			
40			
50			
60			
70			
80			
90			
100			

E.1.3 Table 1.3: Resonant frequency, Quality Factor and Bandwidth for a high Q circuit

	Theoretical (a)	Experimental (b)	Deviation (%), $\frac{a-b}{a} \times 100$
f$_0$			
f$_1$			
f$_2$			
Bandwidth ($f_2 - f_1$)			
Q-factor $\left(\frac{f_0}{\text{Bandwidth}}\right)$			

E.1.4 Table 1.4: The magnitudes of V_C, V_L and V_R at different frequencies for a low Q circuit

Frequency (f) kHz	Peak Voltage, **V**$_R$(V)	Peak Voltage, **V**$_C$(V)	Peak Voltage, **V**$_L$(V)
1			
10			
20			
30			
40			
50			
60			
70			
80			
90			
100			

E.1.5 Table 1.5: Resonant frequency, Quality Factor and Bandwidth for a low Q circuit

	Theoretical (a)	Experimental (b)	Deviation (%), $\frac{a-b}{a} \times 100$
f$_0$			
f$_1$			
f$_2$			
Bandwidth ($f_2 - f_1$)			
Q-factor $\left(\frac{f_0}{\text{Bandwidth}}\right)$			