Lab 2: AC response of RC and RL circuits

A. Objectives

- Investigate capacitive and inductive reactance. Analyze the frequency response of RC and RL circuits.

B. Background

B.1. Impedance:

Impedance (Z) is a measure of the overall opposition of a circuit to current, in other words: how much the circuit impedes the flow of current. It is like resistance, but it also takes into account the effects of capacitance and inductance. Impedance is measured in ohms (Ω).

Unlike resistance, the effects of capacitance and inductance vary with the frequency of the current passing through the circuit and this means impedance varies with frequency. The effect of resistance is constant regardless of frequency.

Impedance can be split into two parts:

- Resistance **R** (the part which is constant regardless of frequency)
- Reactance **X** (the part which varies with frequency due to capacitance and inductance)

The capacitance and inductance cause a phase shift between the current and voltage which means that the resistance and reactance cannot be simply added up to give impedance. Instead, resistance and reactance must be added as vectors to calculate the total impedance.

B.2. Capacitive Reactance:

Capacitive Reactance is a measure of the opposition provided by a capacitor to the flow of charge in a circuit. It varies with the frequency of the input signal and is measured in ohms. Capacitive Reactance is denoted by the symbol $\mathbf{X_C}$.

$$X_C = \frac{1}{2\pi f C}$$

Here, 'f' is the frequency in Hertz (Hz) and 'C' is the capacitance in Farads (F). The inverse relationship between Capacitive Reactance and frequency means that X_C is large at low frequencies and small at high frequencies.

B.3. Inductive Reactance:

Inductive Reactance is a measure of the opposition provided by an inductor to the flow of charge in a circuit. It varies with the frequency of the input signal and is measured in ohms. Inductive Reactance is denoted by the symbol $\mathbf{X_L}$.

$$X_L = 2\pi f L$$

Here, 'f' is the frequency in Hertz (Hz) and 'L' is the capacitance in Henrys (H). As X_L is directly proportional to frequency, Inductive Reactance is small at low frequencies and large at high frequencies.

B.4. Calculating Impedance:

Impedance is generally expressed as a complex number. In Cartesian form, impedance is defined as:

$$Z = R + jX$$

where the real part of impedance is the resistance R and the imaginary part is the reactance X.
For a purely capacitive component, $Z_C = \frac{1}{j\omega C}$ or $Z_C = -\frac{j}{\omega C}$ and for a purely inductive component, $Z_L = j\omega L$, where $\frac{1}{\omega C}$ and ωL are the capacitive and inductive reactances (X_C and X_L) respectively.
Impedance can also be expressed in magnitude and phase form: $|Z|\angle\theta$, where θ is the phase difference between the voltage and the current. The magnitude of the impedance can be expressed as:

$$|Z| = \sqrt{R^2 + X^2}$$

It therefore follows, that for a purely reactive component, |Z| = X.

Experiment 1: AC response of RC circuits

A.1 Apparatus

Components	Instruments
• Resistors: 1×10kΩ • Capacitors: 1×0.1μF	• 1× Bread Board • 1× Function Generator • 1× Dual Channel Oscilloscope

B.1 Procedure

1. Measure the practical values of the circuit components (R,C) shown in Fig.B.1.1 using DMM & LCR meter and note down in the Table 1.1.
2. Construct the circuit 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). Connect the channel 2 at node 'b' (positive red port to node 'b' and negative black port to node 0 i.e. ground).
3. To set 3V peak (6V peak to peak) and 200 Hz in the function generator, observe the generated signal on the oscilloscope screen and fine tune the amplitude and frequency of the input signal generated from the function generator to match the nominal values. **Always set the amplitude after setting the frequency.**

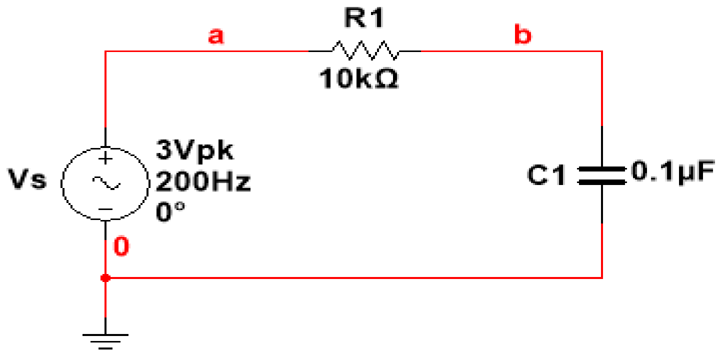

Fig.B.1.1: Circuit diagram of a series RC circuit

4. Channel 2 of the Oscilloscope will show you the voltage drop across C1 and Channel 1 will show you the source voltage VS. To find out the Voltage drop across R1, use **MATH** function to get a signal CH1-CH2.
5. Use **CURSOR** on the signal that was generated using MATH function**,** to find out the peak voltage drop across R1 (V_R). From **measurement,** find out the peak voltage drop across C1 (V_C) and record them in Table 1.2.
6. Change the frequency of the function Generator to the next value in the Frequency column of **Table 1.2.** Keep the input voltage at 3V peak (6V peak-to-peak). And repeat step 5.
7. Repeat step 6 for all the frequency values.

C.1 Simulation

1. In MULTISIM, construct the circuit and do AC analysis over the same range of frequencies as the original experiment. Later, repeat the simulation for any random value of the C1 larger the .3uF but less than .5uF
2. Attach the output graphs in your report.

D.1 Questions

1. What is the relationship between capacitive reactance and frequency?
2. What is the relationship between capacitive reactance and capacitance?
3. If the experiment had been repeated with frequencies 10 times higher than those in Table 1.2, what would the resulting wave shapes in the oscilloscope look like?
4. Using the results from the experiment and the AC analysis simulation, explain what would happen if the AC source were replaced by a 5V DC source. What would be the voltage across the capacitor in that case? What would be the current in the circuit?
5. Derive the expression $X_C = (V_C/V_R) * R$ that was used calculate X_C in the experiment.
6. Compare the two AC response graphs generated in C.1. What can you infer about the relationship between capacitive reactance and capacitance from these graphs? Does the inference support your answer to Question 2?

Experiment 2: AC response of RL circuits

A.2 Apparatus

Components	Instruments
• Resistors: 1×100Ω • Inductors: 1×330µH	• 1× Bread Board • 1× Function Generator • 1× Dual Channel Oscilloscope

B.2 Procedure

1. Measure the practical values of the circuit components (R,L) shown in Fig.B.2.1 using DMM & LCR meter and note down in the Table 2.1
2. Construct the circuit shown in Fig.B.2.1 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). Connect the channel 2 at node 'b' (positive red port to node 'b' and negative black port to node 0 i.e. ground).
3. To set 3V peak (6V peak to peak) and 2 KHz in the function generator, observe the generated signal on the oscilloscope screen and fine tune the amplitude and frequency of the input signal generated from the function generator to match the nominal values. **Always set the amplitude after setting the frequency.**

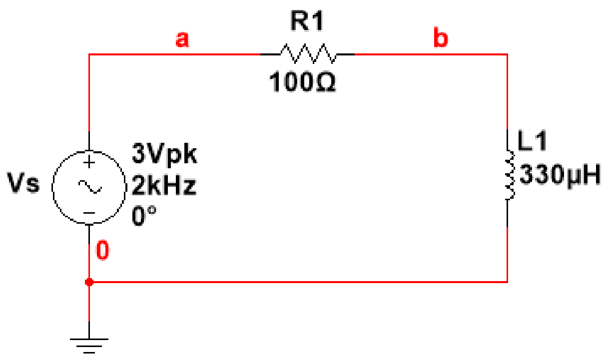

Fig.B.2.1: Circuit diagram of a series RL circuit

4. Channel 2 of the Oscilloscope will show you the voltage drop across L1 and Channel 1 will show you the source voltage VS. To find out the Voltage drop across R1, use **MATH** function to get a signal CH1-CH2.
5. Use **CURSOR** on the signal that was generated using MATH function**,** to find out the peak voltage drop across R1 (V_R). From **measurement,** find out the peak voltage drop across L1 (V_L) and record them in Table 2.2.
6. Change the frequency of the function Generator to the next value in the Frequency column of **Table 2.2.** Keep the input voltage at 3V peak (6V peak-to-peak). And repeat step 5.
7. Repeat step 6 for all the frequency values.

C.2 Simulation

1. In MULTISIM, construct the circuit and do AC analysis over the same range of frequencies as the original experiment. Later, repeat the simulation for any random value of the L1 larger the 560uF but less than 680uF
2. Attach the output graphs in your report.

D.2 Questions

1. What is the relationship between inductive reactance and frequency?
2. What is the relationship between inductive reactance and inductance?
3. If the experiment had been repeated with frequencies 10 times smaller than those in Table 2.2, what would the resulting wave shapes in the oscilloscope look like?
4. Using the results from the experiment and the AC analysis simulation, explain what would happen if the AC source were replaced by a 5V DC source. What would be the voltage across the inductor in that case? What would be the current in the circuit?
5. Derive the expression $X_L = (V_L / V_R) * R$ that was used calculate X_L in the experiment.
6. Compare the two AC response graphs generated in C.2. What can you infer about the relationship between inductive reactance and inductance from these graphs? Does the inference support your answer to Question 2?

E.1 Data Sheet: Lab 2, Experiment 1

Date:	Points:
Remarks:	

Signature of the Instructor

Student Information

Section:	Group:	Status:

E.1.1 Table 1.1: Components' measurements

Components	**Nominal Value (n)**	**Measured Value (m)**	**% of difference**$[\frac{(n-m)}{n} \times 100]$
R	10kΩ		
C	.1uF		

E.1.2 Table 1.2: Comparing Capacitive Reactance and Frequency

Frequency (f) kHz	Peak Voltage, V_R Oscilloscope (V)	Peak Voltage, V_C Oscilloscope (V)	(a) X_C (practical), $[\frac{V_C}{V_R} \times R]$ (Ω)	(b) X_C (theo) $[\frac{1}{2\pi f C}]$ (Ω)	**% of difference** $\frac{(b-a)}{b} \times 100$
0.2					
0.4					
0.6					
0.8					
1					
1.2					
1.4					
1.6					
1.8					
2.0					

E.1.3 Theoretical calculations (for any two frequencies) with the measured values of the components

E.2 Data Sheet: Lab 2, Experiment 2

Date:	Points:
Remarks:	

Signature of the Instructor

Student Information

Section:	Group:	Status:

E.2.1 Table 2.1: Components' measurements

Components	Nominal Value (n)	Measured Value (m)	% of difference[$\frac{(n-m)}{n} \times 100$]
R	100Ω		
L	330uH		

E.2.2 Table 2.2: Comparing Inductive Reactance and Frequency

Frequency (f) kHz	Peak Voltage, V_R Oscilloscope (V)	Peak Voltage, V_L Oscilloscope (V)	(a) X_L (practical), $[\frac{V_L}{V_R} \times R]$ (Ω)	(b) X_L (theo) $[2\pi f L]$ (Ω)	% of difference $\frac{(b-a)}{b} \times 100$
2					
4					
6					
8					
10					
12					
14					
16					
18					
20					

E.2.3 Theoretical calculations (for any two frequencies) with the measured values of the components