Lab 3: Series and Parallel RLC circuits

A. Objectives

- Investigate series and parallel RC, RL, and RLC circuits. Analyze the peak voltage, current and phase relationships between the circuit components.

B. Background

B.1. Voltage and Current in an AC circuit:

The complex impedance in an AC circuit is represented by Z and expressed in Cartesian form by the formula:

$$Z = R + jX$$

where the real part of impedance is the resistance R and the imaginary part is the reactance X.
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: $|Z| = \sqrt{R^2 + X^2}$and the phase can be expressed as:$\theta = tan^{-1}\frac{X}{R}$.
It follows, then, that since Ohm's Law is true for AC circuits, the current flow caused by a voltage V can be given by:

$$\mathbf{I} = \frac{\boldsymbol{V}}{\boldsymbol{Z}}$$

Consider the circuit in **Figure B.1.1**.

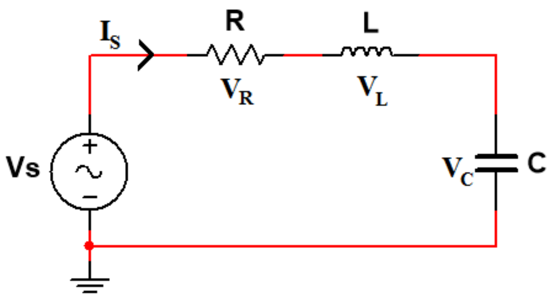


Fig.B.1.1: Series RLC circuit

Here, V_S is the source voltage, $I_S$the source current and V_R, V_L and V_C the voltages across the resistor, inductor and capacitor respectively.The complex voltage across any of the components can be found using the voltage divider rule. The phase relations of the voltages mentioned can be expressed by thephasor diagram in **Figure B.1.2**:

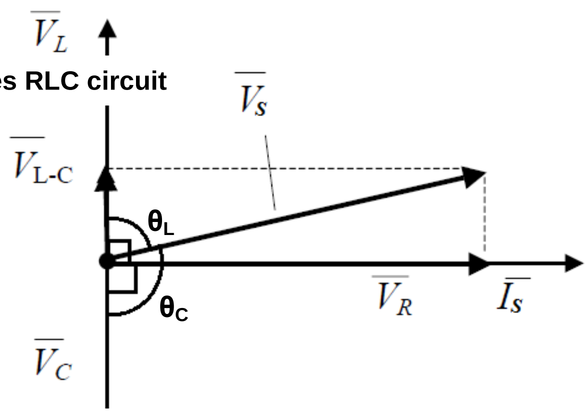


Fig.B.1.2: Phasor Diagram

We can see that V_L and V_C are both 90° out of phase with the circuit current I_S, and θ_L° and θ_C° out of phase with the source voltage respectively. We can also see that the voltage across the resistor is always in phase with the current through the resistor, which, in this case, is the source current.

B.2. Measuring current using an Oscilloscope:

We can indirectly determine the magnitude and phase of the current in any branch of a circuit by using a small sense resistor. The phase angle of the current in the branch will be the same as the phase angle of the voltage across the sense resistor.

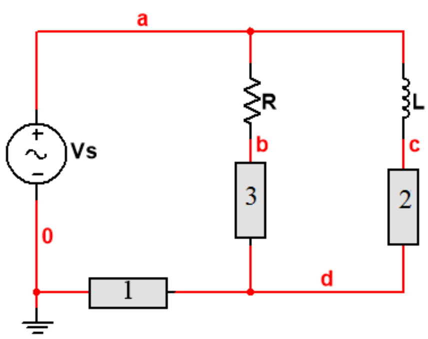


Fig.B.2.1: Sense resistor placement

In the circuit in **Figure B.2.1**, the source current can be measured by adding a resistor 'r1' at Box 1. The resistor chosen must be much smaller than the total circuit impedance so as to have minimal impact on the total current. The phase difference between V_S and V_{r1} will be the phase angle of the circuit current.

Similarly, to find the current through the inductor L, we can add a sense resistor 'r2' at Box 2. The magnitude of the current through L can be determined using Ohm's Law and the phase can be obtained from the phase difference between V_S and V_{r2}.

Experiment 1: Series RLC circuits

A.1 Objective

- To analyze the relationship between the voltage and phase of reactive elements and the source in series RC, RL and RLC circuits.

B.1 Theory

Please refer to part B.1 and B.2 in the Background section.

C.1 Apparatus

Components	Instruments
• Resistors: 1×100Ω • Capacitors: 1×1µF • Inductor: 1x330µH	• 1× Trainer Board • 1× Audio Generator • 1× Dual Channel Oscilloscope • Connecting wires and probes

D.1 Procedure

D.1.1 Measuring the practical value of circuit components and calculating the impedance

1. Measure the practical value of the resistor (R) using DMM and note down the value in Tables 1.1, 1.3 and 1.5. Use the measured values in all your calculations.
2. Measure the practical value of the capacitor (C) using an LCR meter and note down the values in Tables 1.1, and 1.5. Do the same for the inductor (L) and note down the values in Tables 1.3 and 1.5. If an LCR meter is not available, simply note down the nominal values.
3. Calculate the Reactance (**X**), magnitude of total Impedance (**|Z|**) and phase of total Impedance (**Z∠θ°**) in Tables 1.1, 1.3 and 1.5 and note down the values in the respective tables.

D.1.2 Setting Up the Oscilloscope

1. Calibrate both Channel 1 and Channel 2.
2. Set the time/division to 1ms.
3. Set the voltage/division to 1V for both the channels.

D.1.3 Constructing Circuit 1 (Series RC)

1. Construct the circuit shown in **Fig.D.1.1** on the bread board. Use minimal wires.
2. Set 10 kHz Frequency and 3V peak Amplitude (6V peak to peak) in the Audio Generator.
3. Connect Channel 1 of the oscilloscope across the source V_S (positive red port to node ‘a’ and negative black port to node ‘0’ i.e. ground).
4. Observe the generated signal on the oscilloscope screen and fine tune the frequency and amplitude of the input signal generated from the audio 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.

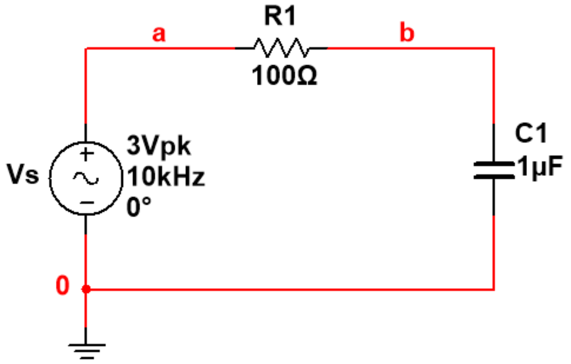


Fig.D.1.1: Series RC circuit

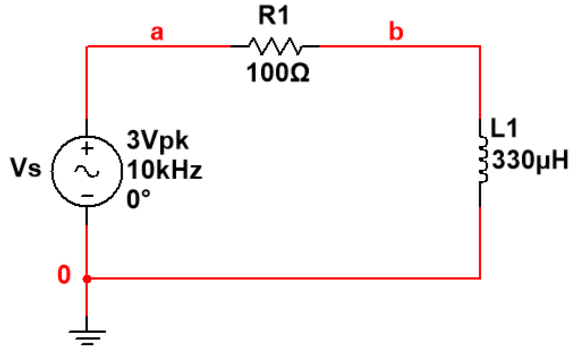


Fig.D.1.2: Series RL circuit

D.1.4 Calculating the voltage across the circuit components

1. Calculate the magnitude and phase of V_C and V_R and note down the values in **Table 1.2.**

D.1.5 Measuring the peak voltage drop and time delay across the capacitor with the oscilloscope

1. Connect the channel 2 at node 'b' (positive red port to node 'b' and negative black port to node 0 i.e. ground).
2. Change the display mode of the oscilloscope so that only Channel 2 is visible on the screen.
3. Measure the peak voltage across C1 as seen on the oscilloscope screen and note down in **Table 1.2**.
4. Change the display mode of the oscilloscope so that both Channels 1 and 2 are visible on the screen.
5. Measure the time between a peak of the source waveshape (V_S – Channel 1) and the next peak of the voltage across C1 (V_C– Channel 2). Note down the time (Delay) in Table 1.2.

D.1.6 Measuring the peak voltage drop and time delay across the resistor with the oscilloscope

1. Swap the positions of the resistor (R1) and the capacitor(C1) in your circuit.
2. Now, use the same method you used in the previous step (D.1.5) to measure the peak voltage across the resistor (R1) and the time (Delay) between the V_S (Channel 1) and V_R (now Channel 2). Note down the values in **Table 1.2**.

D.1.7 Constructing Circuit 2 (Series RL)

1. Construct the circuit shown in **Fig.D.1.2** on the bread board. Use minimal wires.
2. Set 10 kHz Frequency and 3V peak Amplitude (6V peak to peak) in the Audio Generator.
3. Connect Channel 1 of the oscilloscope across the source V_S (positive red port to node 'a' and negative black port to node '0' i.e. ground).

D.1.8 Calculating the voltage across the circuit components

1. Calculate the magnitude and phase of V_L and V_R and note down the values in **Table 1.4.**

D.1.9 Measuring the peak voltage drop and time delay across the inductor with the oscilloscope

1. Connect the channel 2 at node 'b'.
2. Change the display mode of the oscilloscope so that only Channel 2 is visible on the screen.
3. Measure the peak voltage across L1 as seen on the oscilloscope screen and note down in **Table 1.4**.
4. Change the display mode of the oscilloscope so that both Channels 1 and 2 are visible on the screen.
5. Measure the time between a peak of the source waveshape (V_S – Channel 1) and the next peak of the voltage across L1 (V_L – Channel 2). Note down the time (Delay) in **Table 1.4**.

D.1.10 Measuring the peak voltage drop and time delay across the resistor with the oscilloscope

1. Swap the positions of the resistor (R1) and the inductor (L1) in your circuit.
2. Now, use the same method you used in the previous step (D.1.9) to measure the peak voltage across the resistor (R1) and the time (Delay) between the V_S (Channel 1) and V_R (now Channel 2). Note down the values in **Table 1.4**.

D.1.11 Constructing Circuit 3 (Series RLC)

1. Construct the circuit shown in **Fig.D.1.3** on the bread board. Use minimal wires.
2. Set 10 kHz Frequency and 3V peak Amplitude (6V peak to peak) in the Audio Generator.
3. Connect Channel 1 of the oscilloscope across the source V_S (positive red port to node 'a' and negative black port to node '0' i.e. ground).

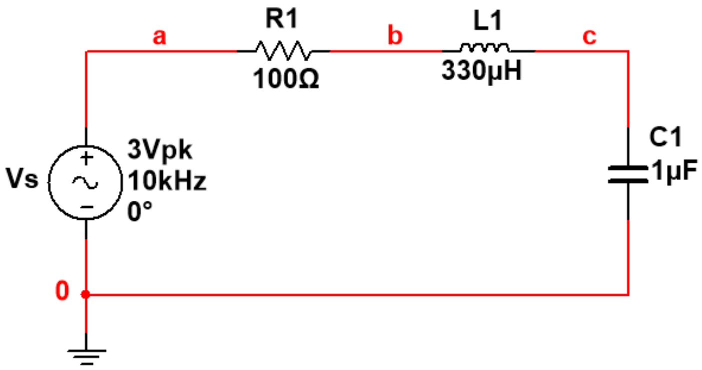


Fig.D.1.3: Series RLC circuit

D.1.12 Calculating the voltage across the circuit components

1. Calculate the magnitude and phase of V_C, V_L and V_R and note down the values in **Table 1.6.**

D.1.13 Measuring the peak voltage drop and time delay across the capacitor with the oscilloscope

1. Connect the channel 2 at node 'c'.
2. Change the display mode of the oscilloscope so that only Channel 2 is visible on the screen.
3. Measure the peak voltage across C1 as seen on the oscilloscope screen and note down in **Table 1.6**.
4. Change the display mode of the oscilloscope so that both Channels 1 and 2 are visible on the screen.
5. Measure the time between a peak of the source waveshape (V_S – Channel 1) and the next peak of the voltage across C1 (V_C– Channel 2). Note down the time (Delay) in **Table 1.6**.

D.1.14 Measuring the peak voltage drop and time delay across the inductor with the oscilloscope

1. Swap the positions of the inductor (L1) and the capacitor (C1) in your circuit.
2. Now, use the same method you used in the previous step (D.1.14) to measure the peak voltage across the inductor (L1) and the time (Delay) between the V_S (Channel 1) and V_L (now Channel 2). Note down the values in **Table 1.6**.

D.1.15 Measuring the peak voltage drop and time delay across the resistor with the oscilloscope

1. Now, swap the positions of the resistor (R1) and the inductor (L1) in the new circuit you constructed in step D.1.14.
2. Use the same method you used in the previous step (D.1.14) to measure the peak voltage across the resistor (R1) and the time (Delay) between the V_S (Channel 1) and V_R (now Channel 2). Note down the values in **Table 1.6**.

D.1.16 Comparing the practical and theoretical values of circuit voltages

1. For each voltage value recorded so far, calculate the phase angle from the Delays (ΔT) using the given formula.
2. Calculate the difference between the practical and theoretical magnitudes and phase angles of the voltages and record the values in the respective tables.

G.1 Questions

1. In step D.1.6, could the required readings have been obtained without switching the positions of the resistor and the capacitor? Explain your answer.
2. Draw the phasor diagrams for the circuits in Fig D.1.1 and Fig D.1.2.
3. How would each of the phasor diagrams change if the source frequency was raised?
4. In case of the series RLC circuit, do the practical readings confirm the theoretical values? If any of the percentage differences are above 10%, suggest 3 possible reasons for the discrepancy.

Experiment 2: Parallel RLC circuits

A.2 Objective

- To analyze the relationship between the current and phase of reactive elements and the source in parallel RC, RL and RLC circuits.

B.2 Theory

Please refer to part B.1 and B.2 in the Background section.

C.2 Apparatus

Components	Instruments
• Resistors: 1×10kΩ, 1x1kΩ • Capacitors: 1x10nF • Inductors: 1× [6 – 14] H	• 1× Trainer Board • 1× Audio Generator • 1× Dual Channel Oscilloscope • Connecting wires and probes

D.2 Procedure

D.2.1 Measuring the practical value of circuit components and calculating the impedance

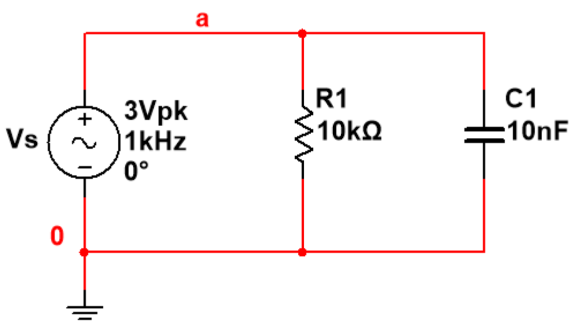
1. Measure the practical value of the resistor (R) using DMM and note down the value in Tables 2.1, 2.3 and 2.5. Use the measured values in all your calculations.
2. Measure the practical value of the capacitor (C) using an LCR meter and note down the values in Tables 2.1, and 2.5. Do the same for the inductor (L) and note down the values in Tables 2.3 and 2.5 and also in Figures D.2.2 and D.2.3. If an LCR meter is not available, simply note down the nominal values.
3. Calculate the Reactance (**X**), magnitude of total Impedance (**|Z|**) and phase of total Impedance (**Z∠θ°**) in Tables 2.1, 2.3 and 2.5 and note down the values in the respective tables.

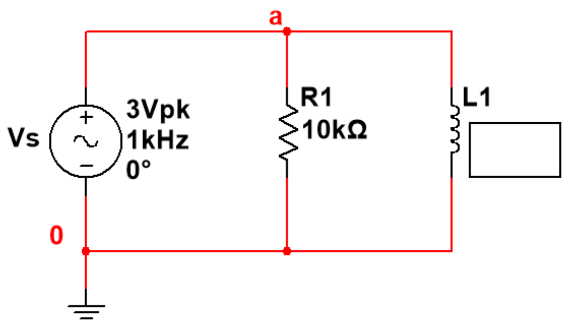
D.2.2 Setting Up the Oscilloscope

1. Calibrate both Channel 1 and Channel 2.
2. Set the time/division to 0.2ms.
3. Set the voltage/division to 1V for both the channels.

D.2.3 Constructing Circuit 1 (Parallel RC)

1. Construct the circuit shown in **Fig.D.2.1** on the bread board. Use minimal wires.
2. Set 1 kHz Frequency and 3V peak Amplitude (6V peak to peak) in the Audio Generator.
3. Connect Channel 1 of the oscilloscope across the source V_S (positive red port to node ‘a’ and negative black port to node ‘0’ i.e. ground).
4. Observe the generated signal on the oscilloscope screen and fine tune the frequency and amplitude of the input signal generated from the audio 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.





D.2.4 Calculating the currents through the different circuit components

1. Calculate the magnitude and phase of I_S (I_{source}), I_C and I_R and note down the values in **Table 2.2.**

D.2.5 Measuring the peak current through the sourceand the time delay with the oscilloscope

1. Use the information in section B.2 to connect the 1kΩsense resistor (r) at suitable point in order to measure the source current, I_S.
2. Connect and use Channel 2 to view the voltage across the sense resistor.
3. Measure the peak voltage across the sense resistor and calculate the peak current using Ohm's Law. Note down both in **Table 2.2**.

Fig.D.2.1: Parallel RC circuit **Fig.D.2.2: Parallel RL circuit**

4. Change the display mode of the oscilloscope so that both Channels 1 and 2 are visible on the screen.
5. Measure the time between a peak of the source waveshape (V_S – Channel 1) and the next peak of the voltage across the sense resistor (V_{sense} - Channel 2). Note down the time (Delay) in **Table 2.2**.

D.2.6 Measuring peak voltage and time delay across the resistorand capacitor with the oscilloscope

1. Now, move the sense resistor to the branch containing R1 and use the same method you used in the previous step (D.2.5) to measure the peak current in the branchand the time (Delay) between V_S (Channel 1) and V_{sense} (Channel 2). Note down the values in **Table 2.2**.
2. Next, move the sense resistor to the branch containing C1 and use it to determine and record the peak current in that branch and the delay.

D.2.7 Constructing Circuit 2 (Parallel RL)

1. Construct the circuit shown in **Fig.D.2.2** on the bread board. To do so, simply replace the capacitor in the previous circuit with one of the provided inductors.
2. Set 1 kHz Frequency and 3V peak Amplitude (6V peak to peak) in the Audio Generator.

D.2.8 Calculating the voltage across the circuit components

1. Calculate the magnitude and phase of I_S, I_L and I_R and note down the values in **Table 2.4.**

D.2.9 Measuring the currents through the components and the phase angles with the oscilloscope

1. Using the same method you used in D.2.5 and D.2.6, use the given sense resistor to determine the peak values of the source current, the current through the resistor R1 and the current through the inductor L1. Record the values in **Table 2.4**.
2. For each case, note down the time (Delay) in **Table 2.4**.

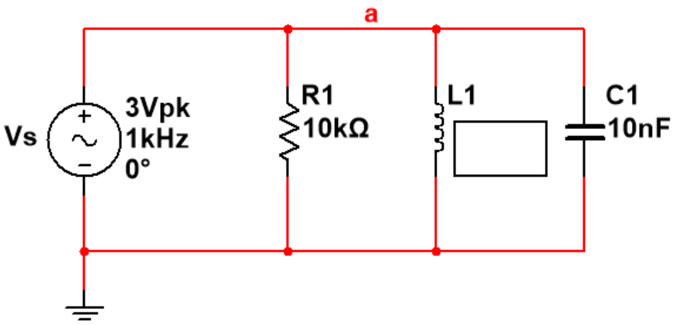


Fig.D.2.3: Parallel RLC circuit

D.2.10 Constructing Circuit 3 (Parallel RLC)

1. Construct the circuit shown in **Fig.D.2.3** on the bread board. Use minimal wires.
2. Set 1 kHz Frequency and 3V peak Amplitude (6V peak to peak) in the Audio Generator.

D.2.11 Calculating the voltage across the circuit components

1. Calculate the magnitude and phase of I_S, I_C,I_L, and I_R and note down the values in **Table 2.6.**

D.2.12 Measuring the currents through the components and the phase angles with the oscilloscope

1. Using the same method you used in D.2.5 and D.2.6, use the given sense resistor to determine the peak values of the source current, the current through the resistor R1, the current through the capacitor C1 and the current through the inductor L1. Record the values in **Table 2.6**.
2. For each case, note down the time (Delay) in **Table 2.6**.

D.2.13 Comparing the practical and theoretical values of circuit currents

1. For each current value recorded so far, calculate the phase angle from the Delays (ΔT) using the given formula.
2. Calculate the difference between the practical and theoretical magnitudes and phase angles of the currents and record the values in the respective tables.

G.2 Questions

1. A 1kΩ sense resistor was used to perform this experiment. Suggest 1 possible advantage and 1 possible disadvantage of using an even smaller (say 10Ω) sense resistor in the first circuit (D.2.1).
2. Draw the phasor diagrams for the circuits in Fig D.2.1 and Fig D.2.2.
3. How would each of the phasor diagrams change if the source frequency was raised?
4. In case of the parallel RLC circuit, do the practical readings 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 3, Experiment 1

Date:	Points:
Remarks:	

Signature of the Instructor

Student Information

Section:	Group:	Status:

E.1.1 Table 1.1: Reactance and Impedance values (series RC circuit)

R (measured)(Ω)	**C (measured)**(F)	**X_C (Theory)** [$\frac{1}{2\pi fC}$] (Ω)	**|Z|**(Ω) [$\sqrt{R^2+X^2}$]	**Z ∠θ°** [$tan^{-1}(\frac{X}{R})$]

E.1.2 Table 1.2: Comparing magnitudes and phases of V_C and V_R

	$\|V_{peak}\|$ (Theory)	**θ** (Theory)	**$\|V_{peak}\|$** (Practical)	**Delay ΔT** (Practical)	**θ (Practical)** [ΔT x f x 360]	**% Difference |V|**	**% Difference θ**
V_C							
V_R							

E.1.3 Table 1.3: Reactance and Impedance values (series RL circuit)

R (measured)(Ω)	**L(measured)**(H)	**X_L (Theory)** [$2\pi fL$] (Ω)	**|Z|**(Ω) [$\sqrt{R^2+X^2}$]	**Z ∠θ°** [$tan^{-1}(\frac{X}{R})$]

E.1.4 Table 1.4: Comparing magnitudes and phases of V_L and V_R

	$\|V_{peak}\|$ (Theory)	**θ** (Theory)	**$\|V_{peak}\|$** (Practical)	**Delay ΔT** (Practical)	**θ (Practical)** [ΔT x f x 360]	**% Difference |V|**	**% Difference θ**
V_L							
V_R							

E.1.5 Table 1.5: Reactance and Impedance values (series RLC circuit)

R (Ω)	**C** (F)	**L** (H)	**X_C (Theory)** [$\frac{1}{2\pi fC}$] (Ω)	**X_L (Theory)** [$2\pi fL$] (Ω)	**|Z|**(Ω) [$\sqrt{R^2+X^2}$]	**Z∠θ°** [$tan^{-1}(\frac{X}{R})$]

E.1.6 Table 1.6: Comparing magnitudes and phases of V_C,V_L and V_R

	$\|V_{peak}\|$ (Theory)	**θ** (Theory)	**$\|V_{peak}\|$** (Practical)	**Delay ΔT** (Practical)	**θ (Practical)** [ΔT x f x 360]	**% Difference |V|**	**% Difference θ**
V_C							
V_L							
V_R							

E.2 Data Sheet: Lab 3, Experiment 2

Date:	Points:
Remarks:	

Signature of the Instructor

Student Information

Section:	Group:	Status:

E.2.1 Table 2.1: Reactance and Impedance values (parallel RC circuit)

R (measured)(Ω)	**C (measured)**(F)	**X_C (Theory)** $[\frac{1}{2\pi fC}]$ (Ω)	**|Z|**(Ω) $[\sqrt{R^2 + X^2}]$	**Z∠θ°** $[tan^{-1}(\frac{X}{R})]$

E.2.2 Table 2.2: Comparing magnitudes and phases of i_C and i_R

	$\|i_{peak}\|$ (Theory)	θ (Theory)	**$V_{sense(peak)}$** (Measured)	**$\|i_{peak}\|$** (Practical)	**Delay ΔT** (Measured)	**θ (Practical)** [ΔT x f x 360]	**% Difference |i|**	**% Difference θ**
i_C								
i_R								
i_S								

E.2.3 Table 2.3: Reactance and Impedance values (parallel RL circuit)

R (measured)(Ω)	**L (measured)**(H)	**X_L (Theory)** [$2\pi fL$] (Ω)	**|Z|**(Ω) $[\sqrt{R^2 + X^2}]$	**Z∠θ°** $[tan^{-1}(\frac{X}{R})]$

E.2.4 Table 2.4: Comparing magnitudes and phases of i_L and i_R

	$\|i_{peak}\|$ (Theory)	**θ** (Theory)	**$V_{sense(peak)}$** (Measured)	**$\|i_{peak}\|$** (Practical)	**Delay ΔT** (Measured)	**θ (Practical)** [ΔT x f x 360]	**% Difference |i|**	**% Difference θ**
i_L								
i_R								
i_S								

E.2.5 Table 2.5: Reactance and Impedance values (parallel RLC circuit)

R (Ω)	**C** (F)	**L** (H)	**X_C (Theory)** $[\frac{1}{2\pi fC}]$ (Ω)	**X_L (Theory)** [$2\pi fL$] (Ω)	**|Z|**(Ω) $[\sqrt{R^2 + X^2}]$	**Z∠θ°** $[tan^{-1}(\frac{X}{R})]$

E.2.6 Table 2.6: Comparing magnitudes and phases of V_C,V_L and V_R

	$\|i_{peak}\|$ (Theory)	**θ** (Theory)	**$V_{sense(peak)}$** (Measured)	**$\|i_{peak}\|$** (Practical)	**Delay ΔT** (Measured)	**θ (Practical)** [ΔT x f x 360]	**% Difference |i|**	**% Difference θ**
i_C								
i_L								
i_R								
i_S								