Faculty of Engineering and Technology

Electrical and Computer Engineering Department

ENEE2103

Circuits and Electronics Lab

Experiment No.4

Sinusoidal Steady State Circuit Analysis

Prepared By: Faten Sultan **ID:** 1202750

Partners:

Ahmad Ghazawneh **ID:** 1201170
Hadeel Froukh **ID:** 1201585

Instructor's Name: Dr.Mohammad Jehad Al Ju'Beh

Teaching assistant: Eng.Bilal Ismail

Section: 2

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Abstract

The aim of this experiment is to calculate the impedance, the current, and the voltage of the elements in the specified circuits, beside to that we examine capacitive and inductive behavior in the circuits, to use their values in analyzing the behavior of a circuit operating at a constant frequency over time. In addition to that we verify the effectiveness of the Circuit theorems in the sinusoidal steady-state, and to measure the power of sinusoidal steady-state circuits.

The method use in this experiment is that all the specified circuits will be connected to the board, and Function Generator will be used to generate different types of electrical waveforms over a different range of frequencies, the Oscilloscope was used to test and display voltage and current signals to measure the phase shift. We will also use Digital Multimeter (DMM) to measure the voltage and the current.

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Theory

Main idea of this experiment is to see the altering of impedances due to various frequencies in sinusoidal steady state circuits and observe the phase shift power of circuit's components.

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1. AC Circuit And DC Circuit

There are two methods of electric current. These are direct current (DC) and alternating current (AC).

Direct current is a method in which electricity always flows in a certain direction. It refers to the flow of electricity obtained from batteries, solar cells, etc.

On the other hand, alternating current (AC) is a method in which the positive and negative sides are constantly switched periodically and the direction of the flow of electricity changes accordingly. This is the flow of electricity obtained from a generator or outlet. The electricity produced at power plants and sent to homes is also transmitted as alternating current.

The diagram below shows the flow of DC and AC electricity. [1]

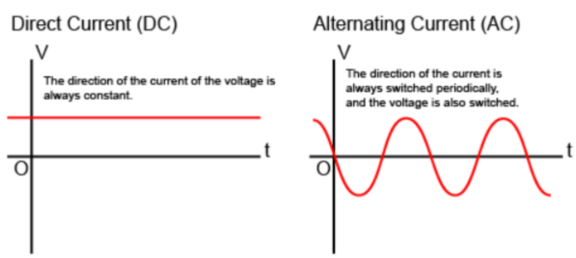


Figure 1:AC And DC Circuit

In direct current, the voltage is always constant, and the electricity flows in a certain direction. In contrast, in alternating current, the voltage periodically changes from positive to negative and from negative to positive, and the direction of the current also periodically changes accordingly. [1]

2. Impedance:

The **Impedance** is denoted by *Z*, and is defined as an electrical impedance that measure of the entire opposition that a circuit or a component of a circuit exhibits to electric current. In the **Alternating Current** circuit, which is known as AC Circuit, the Impedance is a value calculated in **Ohms** that is the combined effect of the circuit's current limiting components within it, for instance the resistance(R), capacitance (C), and inductance (L).

In the **Direct Current** circuit, or DC circuits, the opposition to current flow is called **Resistance** and donated by the letter **R,** but in an AC circuit, it's called as mentioned before Impedance, which is the result of both the circuits **resistive** (R), and **reactive** (X) components and donated by the letter **Z**. [2]

Impedance (Z) is not only a combined effect of the total values of the resistance (R) and the reactance (X) present within an AC circuit. But impedance is also frequency dependent and therefore has a phase angle associated with it.

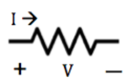
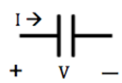
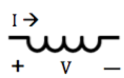
Circuit Element	Symbol	Current-Voltage Relationship in Time	Impedance
Resistor		$V = IR$	R
Capacitor		$I = C\dfrac{dV}{dt}$	$\dfrac{1}{j\omega C}$
Inductor		$V = L\dfrac{dI}{dt}$	$j\omega L$

Figure 2: impedance values for circuit elements

2.1 Impedance in simple circuits:

In the circuit below, there are three simple basic elements: the voltage source, current, and resistors, and the impedance in this case consists of **only real part** while the imaginary part (**reactance**) equals to **zero (zero phase shift Θ = 0).** The real part will be equal to the value of the equivalent **resistors (R)** in the circuit.
Note that Resistors in AC circuits behave the same way they do in DC circuits [3]

We connect the circuit as shown in figure 1,

$$Z = R + 0j$$

$$\Rightarrow Z = R$$

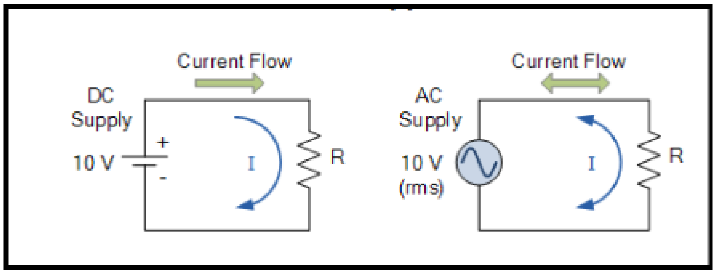


Figure 3: Simple DC and AC circuit

For resistors in AC circuits the direction of the current flowing through them has no effect on the behavior of the resistor so will the phase shift will rise and fall as the voltage rises and falls. Since the current and voltage reach maximum, fall through zero and reach minimum at exactly the same time. They go up and down simultaneously and are said to be "in-phase" as shown below. [3]

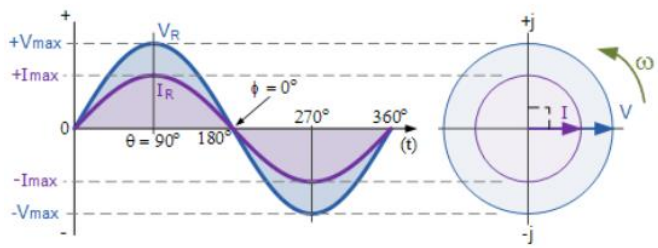


Figure 4:V-I Phase Relationship and Vector Diagram

We can see that at any point along the horizontal axis that the instantaneous voltage and current are in-phase as the current and the voltage reach their maximum values at the same time that is their phase angle θ is 0^o. [3]

2.2 Impedance in RC circuits:

The impedance in the series of RC circuit consists of two elements in the circuit, the **Resistance(R)** and **Capacitive Reactance (Xc)**, and they are related together by the following equation: [3]

$$Z = R - j\,Xc \quad , \text{where } Xc = \frac{1}{2\pi f C}$$

The **magnitude** of the impedance (Z) can be found by:

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

While the **phase shift** can be found by:

$$\theta = tan^{-1}\left(\frac{-Xc}{R}\right)$$

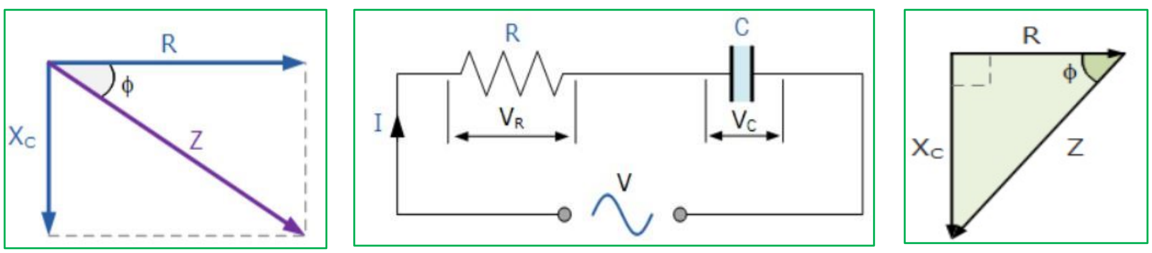


Figure 5:The impedance of series RC circuit

2.3 Impedance in RL circuits:

The impedance in the series of RL circuit is the same as the RC circuit includes two parts, the **Resistance(R)** and **Inductive Reactance (XL)** as shown in the following equation:

$$Z = R + j\,Xl \quad , \text{where } Xl = 2\pi f L$$

And the **magnitude** of the impedance (Z) is:

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

While the **phase shift** is:

$$\theta = tan^{-1}(\frac{Xl}{R})$$

Figure 6: RC Circuit

Note That: The electrical relationship between voltage, current, and impedance is called Ohm's law. The following equation represents Ohm's Low:

$$V = ZI$$

The phase shift of the simple circuit (RC) is **zero**, which means that the voltage and the current waves are **in phase**, while in capacitive circuits is negative (negative angle) which means that the **current leads the voltage**, and in the inductive circuits is positive (positive angle), As **the current lags the voltage** in other [3]

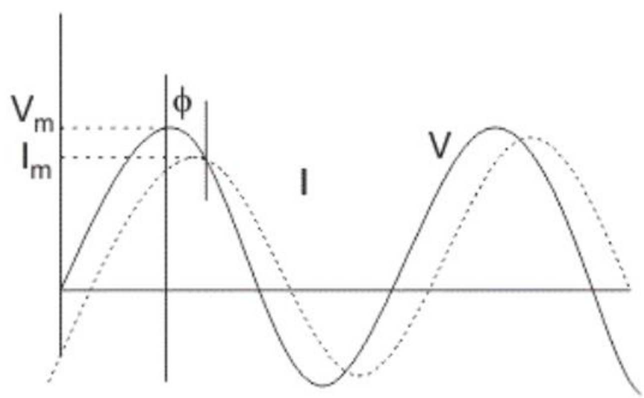


Figure 7:phase shift for RL circuit with voltage leads current in current

In CONCLUSION: In case of pure resistive circuit, the phase angle between voltage and current is zero and in case of pure inductive circuit, phase angle is 90o but when we combine both resistance and inductor, the phase angle of a series RL circuit is between 0o to 90°. [3]

3. Capacitive and inductive behavior:

For series RLC circuit, the impedance can be found by the sum of the **resistance** (R), the **Inductive Reactance (XL),** the **Capacitive Reactance (Xc).**

Capacitive means like a capacitor in an AC circuit – **current leads voltage**.

Inductive means like an inductor in an AC circuit – **current lags voltage** [4]

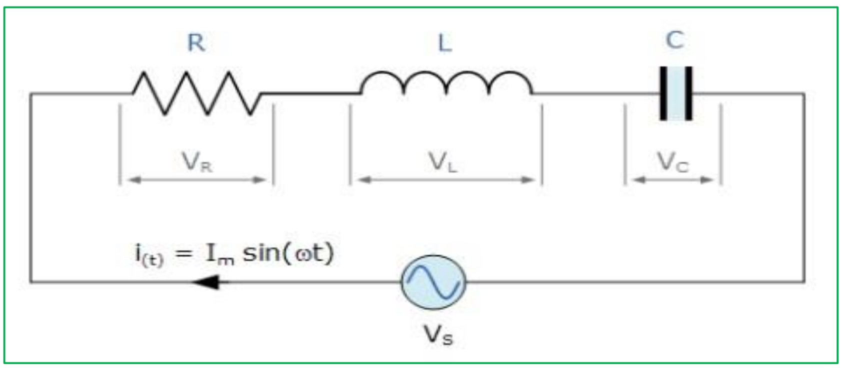


Figure 8: series RLC Circuit

The **impedance equation** as the following:

$$Z = R + j\,(Xl - Xc) \quad , \text{where } Xl = 2\pi f L \text{ and } Xc = \frac{1}{2\pi f C} \qquad (11)$$

And the **magnitude** of the impedance (Z) is:

$$|Z| = \sqrt{R^2 + (XL - Xc)^2} \qquad (12)$$

While the **phase shift** is:

$$\theta = tan^{-1}\left(\frac{Xl - Xc}{R}\right) \qquad (13)$$

If the phase shift of the impedance is negative, this means that **current leads the voltage,** in other word, **capacitive circuit**. While if the phase shift is positive, the circuit considered as **inductive circuit**. [4]

This is the summary for all points discussed above.

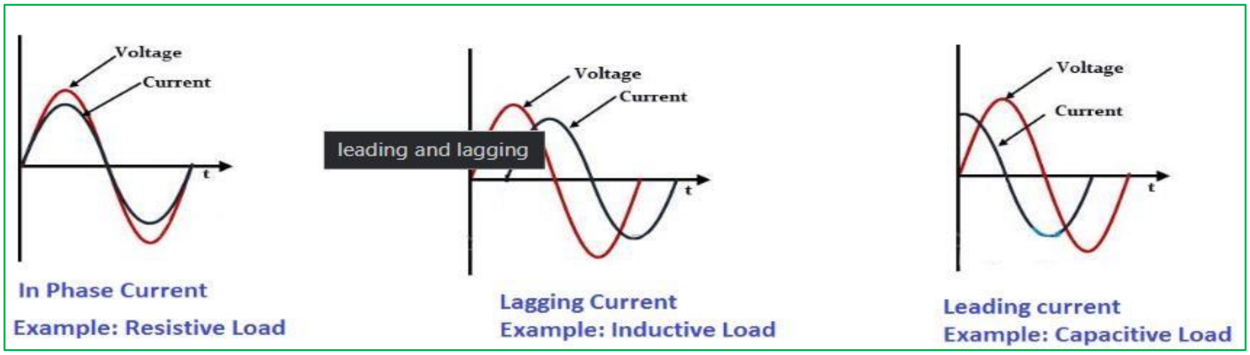


Figure 9: The phase shift of simple, capacitive, and inductive circuits..

4. Sinusoidal steady state power:

In the DC circuits, the voltage and the current are generally constant, that is not varying with time as there is no sinusoidal waveform associated with the supply. But in the AC circuits, the voltage and current waveforms are sinusoidal so their amplitudes are constantly changing over time. **[6]**

4.1 Average Power:

The average power, also known as **real power** or **active power** perform the "real work" within an electrical circuit. Average power is measured in **watts**, and defines the power consumed by the resistive part of a circuit. The equation of the average power is the following: **[6]**

$$\boldsymbol{P_{avg} = \frac{1}{2} V_m I_m \cos(\theta)}, \ \boldsymbol{where\ \theta: between\ the\ V\ \&\ I}$$

Since $V_{rms} = \frac{Vm}{\sqrt{2}}\ and\ I_{rms} = \frac{Im}{\sqrt{2}}$, we can represent the average power as:

$$P_{avg} = V_{rms} I_{rms} \cos(\theta)$$

Note that: The average power of the capacitor or inductor in the AC circuit is equals to **Zero**.

4.2 Reactive Power:

Reactive power (Q), (sometimes called **wattles power**) is the power consumed in an AC circuit that does not perform any useful work but has a big effect on the phase shift between the voltage and current waveforms. Reactive power is linked to the reactance produced by inductors and capacitors and counteracts the effects of real power. **Reactive power does not exist in DC circuits. [6]**

Reactive Power in an AC Circuit is as the following:

$$P_{avg} = \frac{1}{2} V_m I_m \sin(\theta), \text{ where } \theta: \text{between the } V \,\&\, I$$

We can represent the Reactive power in terms of V_{rms} *and* I_{rms} as the following:

$$P_{avg} = V_{rms} I_{rms} \sin(\theta)$$

4.3 Power Factor:

Power factor is an important part of an AC circuit that can also be expressed in terms of circuit impedance or circuit power. Power factor is defined as the ratio of real power (P) to apparent power. [7]

$$\text{Power Factor} = \frac{P_{avg}}{VI} = \cos(\theta)$$

Procedure and Data analysis

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1. Impedance:

The idea of this part is to measure the impedance in different types of AC circuits, such as simple circuit, RC circuit and RL circuit using **DMM** by measuring the total voltage and current. In addition, to find the phase shift between the total voltage and current by using **Oscilloscope**.

1.1 Impedance in simple circuit:

Experimental Results:

Initially, the circuit in (Figure 9) was connected on the board, with a value of resistor set to Rx =2.2 kΩ, R1 = 1K with Voltage 10 peak-peak and 1000 Hz.
So we set the signal generator to generate a sinusoidal waveform with amplitude 5 volts and frequency 1 kHz
We measured the total impedance of the circuit using DMM by measuring the total voltage and the current and then found the phase shift between total voltage and current using the oscilloscope

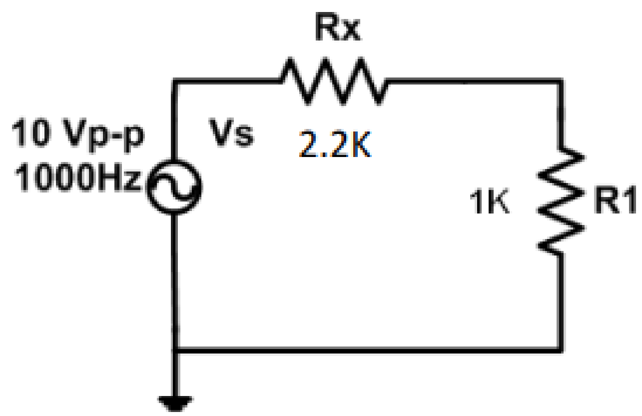

Figure 10:RC circuit part 1

In real part it is shown like this:

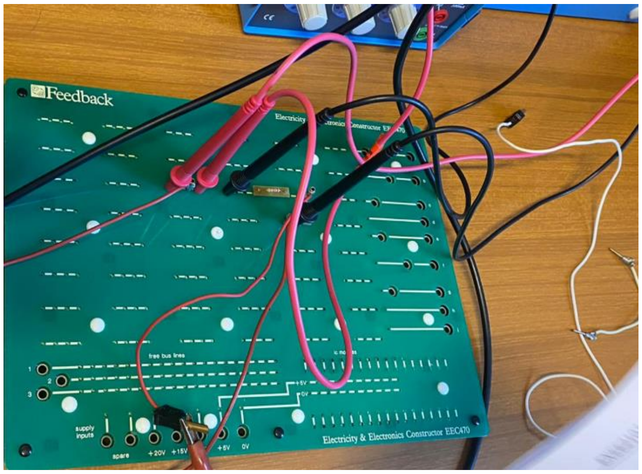

Figure 11: Actual RC Circuit

This circuit has the following phase shift:

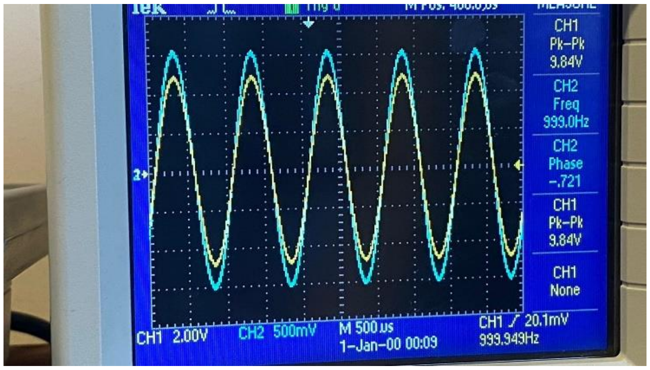

Figure 12:The total voltage and current waves in Oscilloscope when F=1000 Hz

We repeated the experiment using the same steps however with different signal frequencies: 500 Hz, 1500 Hz.

- **When f=500 Hz:**

When the frequency is equals to 500 Hz, the waves of the total voltage and current were in phase. In other word, the **phase shift was equals to zero** as shown in the following figure:

The total voltage and current in the circuit which is $\boldsymbol{V_{rms}} = \mathbf{3.379}\ \boldsymbol{V}$ and $\boldsymbol{I_{rms}} = \mathbf{1.06}\ \boldsymbol{mA}$ as shown:

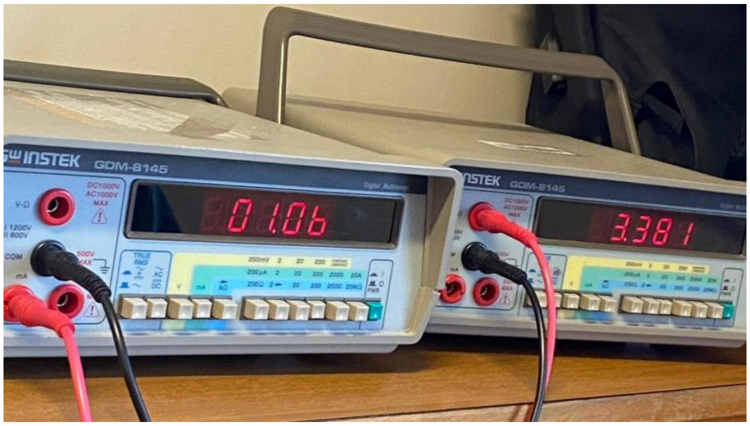

Figure 13:The total voltage and current values of the simple circuit using DMM, f=500 Hz

In order to calculate the **total impedance** for this AC circuit, the total impedance can be calculated as:

$$Z_{eq} = V/I = 3.381 / (1.06*10^{-3}) = 3.377\text{Kohm}$$

- **When f=1000 Hz:**

When the frequency was 1000Hz, the waves of the total current and the voltage still in phase with **zero phase shift,** and the value of the total voltage and current **still the same** , $\boldsymbol{V_{rms} = 3.381\ V}$ and $\boldsymbol{I_{rms} = 1.06\ mA}$**, and the total impedance is as the following:**

$$Z_{eq} = V/I = 3.381 / (1.06*10^{-3}) = 3.377\text{Kohm}$$

- **When f=1500 Hz:**

When the frequency was changed to 1500Hz, the waves of the total current and the voltage did not change ,still in phase with **zero phase shift,** and the value of the total voltage and current still the **same,**$\boldsymbol{V_{rms} = 3.381\ V}$ and $\boldsymbol{I_{rms} = 1.06\ mA}$**, and the total impedance** is as the following**:**

$$Z_{eq} = V/I = 3.381 / (1.06*10^{-3}) = 3.377\text{Kohm}$$

Note that the values of current and voltage were the same for all values of frequency “500-1000-1500” and the phase shift is the same for these three parts, with a zero phase shift.
We can summarize that the **total impedance** of the AC circuit is the **same** regardless to the value of the frequency **(500 Hz, 1 kHz, and 1500Hz)** using the function generator. The **total impedance** of the circuit is:

1. Frequency = 500 Hz → Z= 3.381 $\boldsymbol{Kohm}$.
2. Frequency = 1000 Hz → Z= 3.381$\boldsymbol{Kohm}$.
3. Frequency = 1500 Hz → Z= 3.381$\boldsymbol{Kohm}$.

In addition, the **phase shift** zero in all cases, since the waves of total voltage and current were **in phase** because the circuit contains only resistors without any inductors or capacitors.

Table 1: Impedance of the simple circuit practical results

f [Hz]	V_{rms}	I_{rms}	Δt	Phase Shift
500	3.379 V	1.06 mA	0	0
1k	3.379 V	1.06 mA	0	0
1.5k	3.379 V	1.06 mA	0	0

Theoretical Results:

In the simple circuits which contain only the basic components, without any capacitors and inductors, the total impedance will be the equal to the equivalent resistor of the circuit. Since the circuit in (***Figure 10)*** has resistors in series, then the equivalent resistor will be the sum of the resistors with zero phase shift as the following:

$$\boldsymbol{Total\ impedance\ Z = R_{eq} = Rx + R1 = 2.2k + 1k = 3.2\ Kohm}$$

.

Table 2:Comparison between experimental the theoretical results in the simple circuit

	Frequency	Impedance	Phase Shift
Theoretically	*500 Hz*	*3.2 K ohm*	0
Experimentally		3.377 $Kohm$	0
Theoretically	*1000 Hz*	*3.2 K ohm*	0
Experimentally		3.377 $Kohm$	0
Theoretically	*1500 Hz*	3.2 K ohm	0
Experimentally		3.377 $Kohm$	0

1.2 Impedance of RC circuit:

Experimental Results:

We connect the same circuit (as shown in figure 9) with a capacitor equals 100nF connected in series with the circuit, and the value of Rx = 2.2 K ohm as shown:

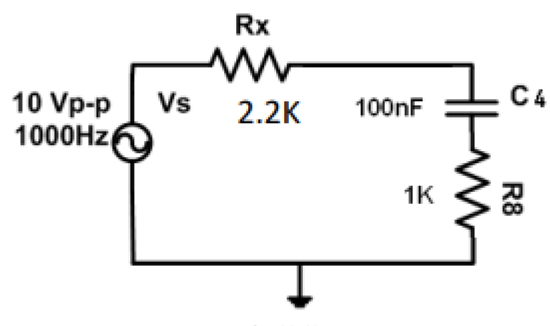

Figure 14: Simple RC Circuit

In the series RC circuit, the impedance of the circuit will be the sum of the **resistors (R)** and the **capacitive reactance (Xc).** In addition, the phase shift will be negative which means that the current leads the voltage.

- **When f=500 Hz:**

When the frequency equals to 500 Hz, the total current equals to 0.835 mA, while the total voltage equals to 3.628V. The **phase shift** of the circuit is 42.9 degree, the current **leads** the voltage. The **total impedance** is measured as the following:

$$Z_{eq} = V/I = 3.628 / (0.835*10^{-3}) = 4.345 \text{Kohm}$$

The figure below shows the phase difference we got:

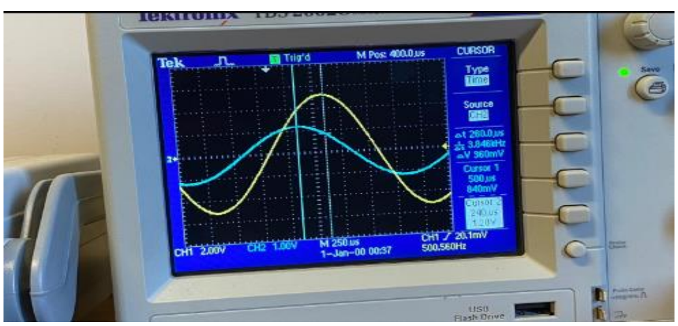

Figure 15:phase shift for The voltage and current waves of RC circuit when F=500 Hz

The total voltage and current in the RC circuit, $= \mathbf{3.628}\,\boldsymbol{V}$ and $\boldsymbol{I_{rms}} = \mathbf{0.835}\boldsymbol{mA}$ as shown:

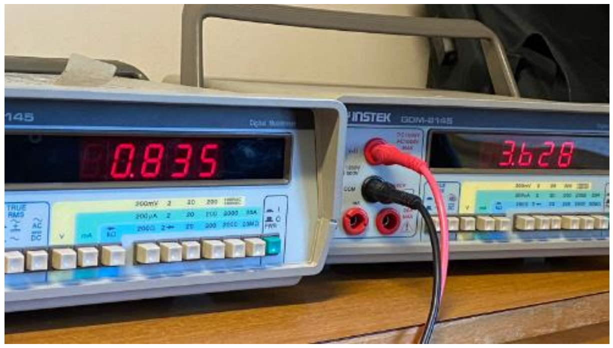

Figure 16: Voltage and current values for a frequency of 500Hz

- **When f=1000 Hz:**

When the frequency was changed to 1 kHz, the **total current** and **voltage** were changed to 3.614 V and 0.9357 mA, and **phase shift** became 24.8 degree. The **total impedance** calculated as the following:

$$\mathbf{Z_{eq} = V/I = 3.614 / (0.9357 * 10^{-3}) = 3.862Kohm}$$

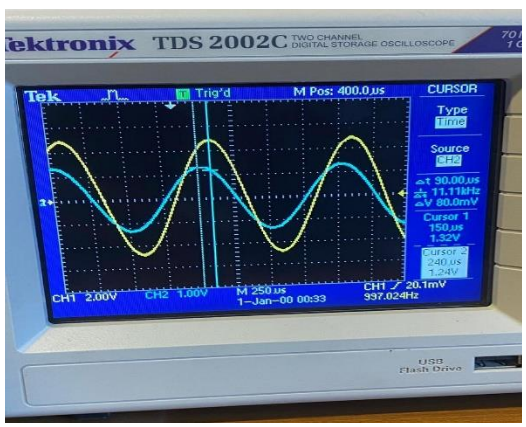

Figure 17:The voltage and current waves of RC circuit when F=1000 Hz

- **When f=1500 Hz:**

When the frequency was changed to 1500Hz, the **total voltage** and **current** were also changed to 3.610 V and 1.078 mA respectively. While the **phase shift** became 17.7 degree. The **total impedance** measured as:

$$\mathbf{Z_{eq} = V/I = 3.610 / (1.078 * 10^{-3}) = 3.349Kohm}$$

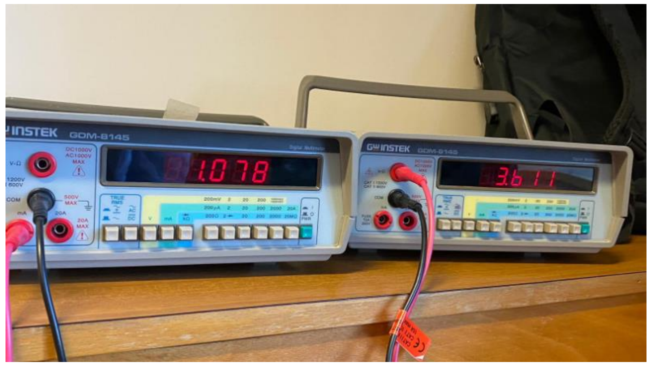

Figure 18:The total voltage and current of RC circuit values using DMM, f=1500 Hz

From the values we have got in the experimental results, we have noticed that the total impedance changed once the frequency change **(500 Hz, 1000Hz, and 1500 Hz)** using the function generator. Since in the RC circuits, the impedance calculated by the sum of the resistors and the capacitive reactance (Xc) which depends on the frequency of the circuit as the following:

$$Z = R - j\,X_c \quad , \text{where } X_c = \frac{1}{2\pi f C}$$

Also, the **phase shift** is negative in all cases since its capacitive circuit. In other word, the current leads the voltage.

Table 3: Results in Impedance of RC circuit:

f [Hz]	V_{rms}	I_{rms}	Z	Phase Shift	ΔT
500	3.628 V	0.835 mA	4.345Kohm	42.9 degree	160us
1k	3.614 V	0.9357 mA	3.862Kohm	24.1 degree	90 us
1.5k	3.610 V	1.078 mA	3.349Kohm	17.7 degree	66.1 us

Where ΔT has been calculated using the following equation:

$$\Delta T = \frac{phase\ shift}{360 * \text{freq}}$$

Theoretical Results:

As mentioned before, In the AC circuits, the total impedance can be calculated by the using the following:

$$R_{eq} = 2.2\ K + 1\ K = 3.2\ K\ ohm.$$

- **Frequency = 500 Hz:**

$$\text{Xc} = \frac{1}{2*\pi*f*c} = \frac{1}{2*\pi*500*100nf} = \mathbf{3.183\ Kohm}$$

So, the **total impedance**:

$$Z = \boldsymbol{R - j\,Xc} = 3.2 - j\ 3.183\ Kohm.$$

The **magnitude** of the total impedance is:

$$|Z| = \sqrt{\boldsymbol{R^2 + XC^2}} = \sqrt{3.2^2 + 3.18^2} = \mathbf{4.511}\ \boldsymbol{Kohm}.$$

And the **phase** is:

$$\text{Phase Shift} = tan^{-1}\frac{Xc}{R} = tan^{-1}\frac{-3.18}{3.2} = \text{-44.820 degrees}$$

Table 4: Comparison between results in the RC circuit for 500HZ

	Frequency	Impedance	Phase Shift
Theoretically	*500 Hz*	*4.511 K ohm*	*-44.8 degree*
Experimentally		4.345Kohm	*42.9 degree*

- **Frequency = 1000 Hz:**

$$\text{Xc} = \frac{1}{2*\pi*f*c} = \frac{1}{2*\pi*1K*100nf} = \mathbf{1.592\ Kohm}$$

So, the **total impedance:**

$$Z = \boldsymbol{R - j\,Xc} = 3.2 - j\ 1.59\ Kohm.$$

While the **magnitude** of the total impedance is:

$$|Z| = \sqrt{(R^2+X^2)} = \sqrt{(3.2^2+1.592^2)}\text{K} = 3.574\ \text{K}\ \Omega$$

And the **phase** is:

$$\text{Phase Shift} = tan^{-1}\frac{Xc}{R} = tan^{-1}\frac{-1.592}{3.2} = \text{-26.45 degrees}$$

.

Table 5: Comparison between results in the RC circuit for 1000HZ

Theoretically	*1000 Hz*	*3.574 K ohm*	*-26.4 degree*
Experimentally		3.585 $Kohm$	*-25.8 degree*
	Frequency	**Impedance**	**Phase Shift**

- **Frequency = 1500 Hz:**

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(1500) * 100 * 10^{-9}} = \mathbf{1.06\ K\ ohm}.$$

So, the **total impedance:**

$$Z = \boldsymbol{R - j\,Xc} = 3.2 - j\,1.06\ Kohm.$$

While the **magnitude** of the total impedance is:

$$|Z| = \sqrt{\boldsymbol{R^2 + XC^2}} = \sqrt{3.2^2 + 1.06^2} = \mathbf{3.37\ Kohm}.$$

And the **phase** is:

$$\boldsymbol{\theta = tan^{-1}(\frac{-Xc}{R}) = tan^{-1}\left(\frac{-1.06}{2.2}\right) = -18.32\ degree}.$$

Table 6:: Comparison between results in the RC circuit for 1500HZ

Theoretically	*1500 Hz*	*3.37 K ohm*	*-18.3 degree*
Experimentally		3.37 $Kohm$	*-17.3 degree*
	Frequency	**Impedance**	**Phase Shift**

Note: From the above table, it is noticed that the results of theoretical part is **almost the same** from the experimental ones, they differ by a very small values ±0.5 and this may return to during the connection the values for capacitor , resistor or either the frequency is not exactly accurate

1.3 Impedance of RL circuit:

Experimental Results:

We connect the circuit the same as before however here we have to remove capacitor and replace it with an inductor.

We connect inductor 400 mH in series with two resistors, and the value of Rx changed to **0.47 k ohm** as shown the next figure:

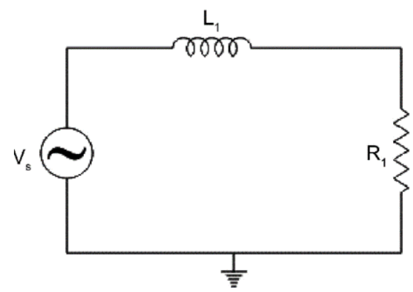

Figure 19:Series RL circuit

In the series RL circuit, the impedance of the circuit will be the sum of the **resistors (R)** and the **inductive reactance (XL).** In addition, the phase shift will be positive which means that the current lags the voltage.

- **When f=500 Hz:**

When the frequency was set to 500 Hz by the function generator, the total current equals to 1.807 mA while the total voltage 3.57 V. The phase shift of the series RL circuit is equals to 41.2 degree, which means that the **current lags the** voltage by 41.2 degree.

And the total impedance can be measured as the following:

$$\mathbf{Z_{eq}= \frac{V}{I} = \frac{3.57}{1.807*10^{-3}} = 1.97\ Kohm}$$

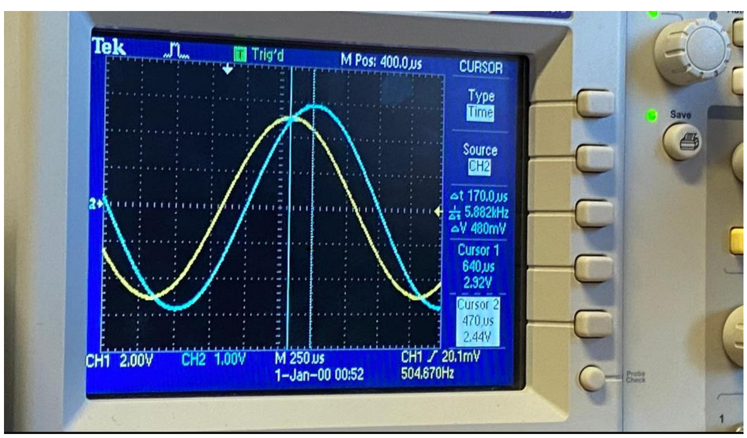

Figure 20: The voltage and current waves of RL circuit when F=500 Hz

- **When f=1000 Hz:**

When the frequency is changed to 1000 Hz, both voltage and current have changed to 3.56 V and 1.215 mA respectively. While the phase shift was equals to 62.8 degree (**current lags the** voltage by 62.8 degree).

To measure the **total impedance**:

$$Z_{eq} = \frac{V}{I} = \frac{3.56}{1.215 * 10^{-3}} = 2.95\ Kohm$$

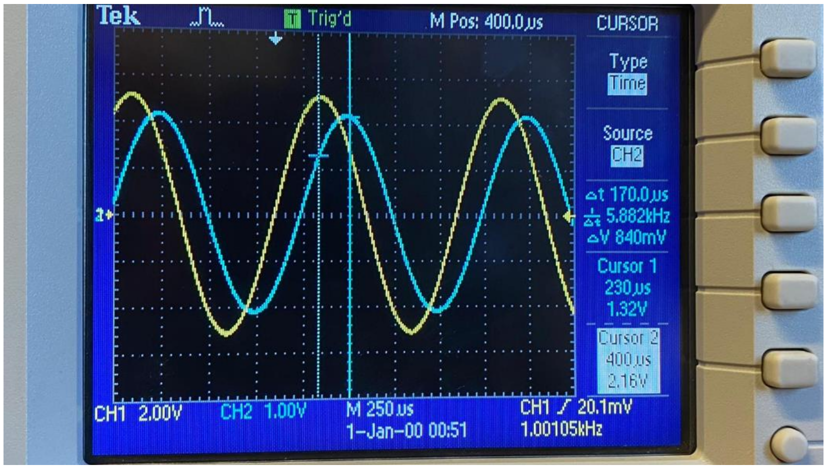

Figure 21:The voltage and current waves of RL circuit when F=1000 Hz

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- **When f=1500 Hz:**

When the frequency is changed to 1000 Hz, both voltage and current have changed to 3.54 V and 0.882 mA respectively. While the phase shift was equals to 69.9 degree (**current lags the** voltage by 69.9degree).

To measure the total impedance:

$$Z_{eq} = \frac{V}{I} = \frac{3.54}{0.882 * 10^{-3}} = 4.01\ Kohm$$

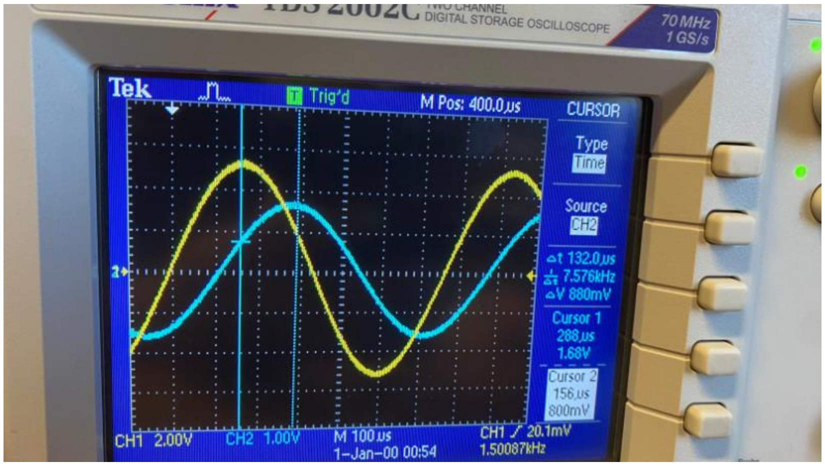


Figure 22:Figure 20:The voltage and current waves of RL circuit when F=1500 Hz

During the experimental, we can summarize that the total impedance changed once the frequency change **(500 Hz, 1000 Hz, and 1500 Hz)** using the function generator, because in the RL circuits, the total impedance calculated by the inductive reactance(XL), which also depends on the value of the frequency as shown. In other words, when changing the frequency, the total impedance will be changed automatically by using the following equation:

The first equation: Z= R + jXl

The second equation: Xl=2$\pi f L$

Table 7:Impedance of the RL circuit practical results.

f [Hz]	V_{rms}	I_{rms}	Δt	Phase Shift	Z
500	3.57 V	2.032 mA	111.5us	41.2 degree	$\mathbf{1.97\ Kohm}$
1000	3.614V	1.506 mA	170us	62.8 degree	$\mathbf{2.95\ Kohm}$
1500	3.634 V	1.35 mA	189.21 us	69.9 degree.	$4.\mathbf{01\ Kohm}$

Where ΔT has been calculated using the following equation:

$$\Delta T = \frac{phase\ shift}{360 * \text{freq}}$$

Theoretical Results:

Calculating the value of the total impedance:

$$R_{eq} = 0.47\ K + 1\ K = 1.47\ K\ ohm.$$

- **Frequency = 500 Hz:**

$$X_l = 2\pi f L = 2\pi * 500 * 400 * 10^{-3} = 1.25\ \boldsymbol{K\ ohm}.$$

So, the **total impedance**:

$$Z = \boldsymbol{R + j\ Xl} = 1.47 + j\ 1.25\ Kohm.$$

While the **magnitude** of the total impedance is:

$$|Z| = \sqrt{\boldsymbol{R^2 + Xl^2}} = \sqrt{1.47^2 + 1.25^2} = \boldsymbol{1.934\ Kohm}.$$

And the **phase** is:

$$\boldsymbol{\theta = tan^{-1}\left(\frac{Xl}{R}\right) = tan^{-1}\left(\frac{1.25}{1.47}\right) = 40.5\ degree}.$$

- **Frequency = 1000 Hz:**

$$X_l = 2\pi f L = 2\pi * 1000 * 400 * 10^{-3} = 2.512\ \boldsymbol{K\ ohm}.$$

So, the **total impedance**:

$$Z = \boldsymbol{R + j\ Xl} = 1.47 + j\ 2.512\ Kohm.$$

While the **magnitude** of the total impedance is:

$$|Z| = \sqrt{\boldsymbol{R^2 + XC^2}} = \sqrt{1.47^2 + 2.512^2} = \boldsymbol{2.91\ Kohm}.$$

And the **phase** is:

$$\boldsymbol{\theta = tan^{-1}\left(\frac{Xl}{R}\right) = tan^{-1}\left(\frac{2.512}{1.47}\right) = 59.66\ degree}.$$

- **Frequency = 1500 Hz:**

$$X_l = 2\pi f L = 2\pi * 1500 * 400 * 10^{-3} = 3.77\ \boldsymbol{K\ ohm}.$$

So, the **total impedance**:

$$Z = \boldsymbol{R + j\ Xl} = 3.2 + j\ 3.77\ Kohm.$$

While the **magnitude** of the total impedance is:

$$|Z| = \sqrt{\boldsymbol{R^2 + XC^2}} = \sqrt{1.47^2 + 3.77^2} = \mathbf{4.04}\ \boldsymbol{Kohm}.$$

And the **phase** is:

$$\boldsymbol{\theta = tan^{-1}(\frac{Xl}{R}) = tan^{-1}\left(\frac{3.77}{2.2}\right) = 68.9\ degree}.$$

Table 8:Comparison between experimental the theoretical results in the RL circuit.

	Frequency	Impedance	Phase Shift
Theoretically	*500 Hz*	1.934 $Kohm$	*40.5 degree*
Experimentally		1.97 $Kohm$	*41.2 degree*
Theoretically	*1000 Hz*	2.91 $Kohm$	59.66 $degree$
Experimentally		2.95 $Kohm$	*62.8 degree*
Theoretically	*1500 Hz*	4.04 $Kohm$	68.9 $degree$
Experimentally		4.01 $Kohm$.	*69.6 degree*

Note: From the above table, we can realize that the results from theoretical part is very close and almost the same as experimental values, which means that our **results are true**.

2. Capacitive and inductive behavior:

In this part we will find the phase shift between the total voltage and current, and to determine the behavior of the RLC circuit in relation to the capacitive, inductive or resistive circuit. Initially, the RLC circuit in (Figure 22) was connected in the board, and a sinusoidal waveform with amplitude 5 volts was generated using the function generator.

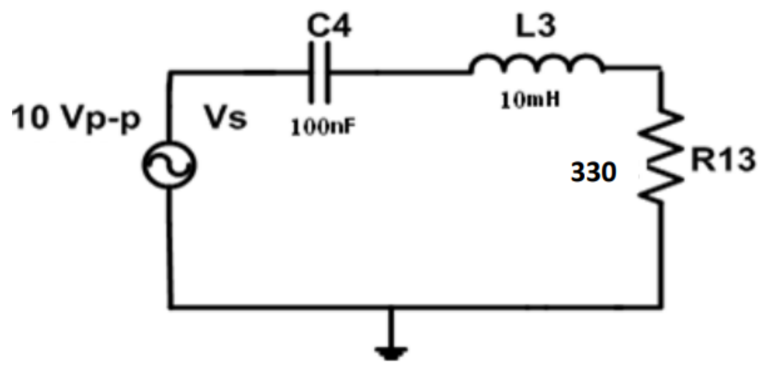


Figure 23: RLC Circuit

Experimental Results:

- **Frequency = 1000Hz:**

When the frequency is 1000 Hz, the phase shift between the voltage and frequency is 77.3 degree, with delta time is equal to 250us which means that the circuit is **capacitive.**

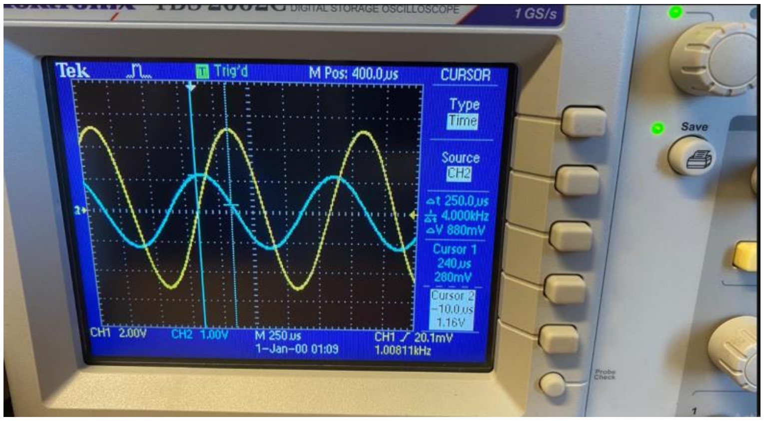


Figure 24:The voltage and current waves of RLC circuit when F=1000 H

- **Frequency = 2000Hz:**

When Frequency equals to 2000 Hz, the phase shift changed to 60.3 degree, with delta time is equal to 88us. The circuit is consider **capacitive** circuit.

- **Frequency = 4000Hz:**

The phase shift changed to 20.7 degree, and delta time is equal to 19us. The circuit is consider **capacitive** circuit.

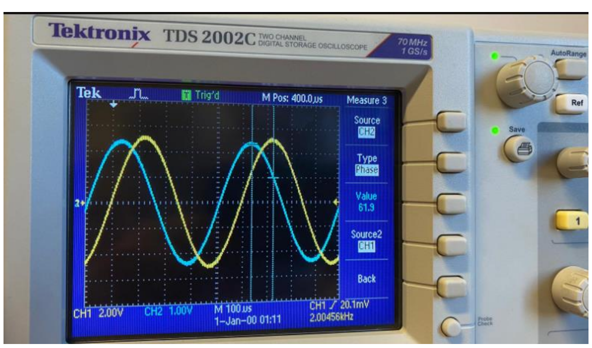


Figure 25:phase shift for 2000HZ

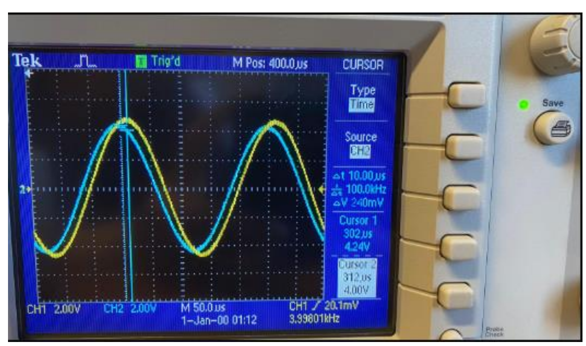


Figure 26:phase shift for 4000HZ

- **Frequency = fo:**

When the frequency equals to the resonance frequency, the phase shift between the voltage source and the current becomes almost zero, in other words, the phase shift will be in phase:

$Resonance\ Frequency\ f0$ (Theoretically) = $\frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(100n)(10m)}}$ = 5.035 KHz

$Resonance\ Frequency\ f0$ experimentally = 4.848 KHz.

Note that: $\boldsymbol{Resonance\ Frequency}$ **experimentally can be obtained when the voltage and current put in phase "the phase shift between them is zero degree as shown below**

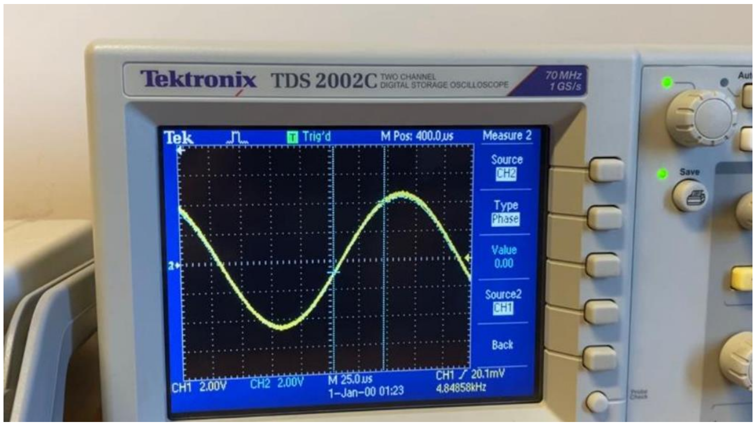


Figure 27:The voltage and current waves of RLC circuit when F=4848Hz

- **Frequency = 6000Hz:**

  When the frequency is 6000 Hz, which is greater than the resonance frequency, the circuits became **inductive** circuit, with phase shift equals to 21.1 degree.

- **Frequency = 8000Hz:**

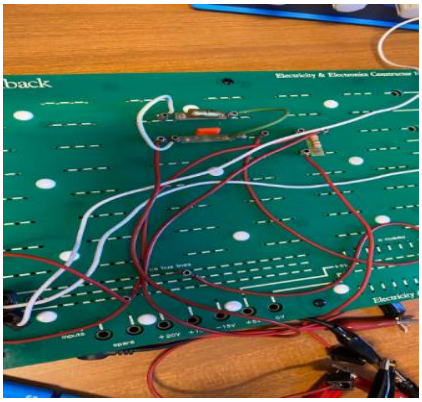
  When the frequency is 8000 Hz, the circuit still **inductive** with 44.7 degree.

- **Doubling the capacitor:**

When doubling the value of the capacitor “adding another 100nF,” and connecting it **in parallel** to the original one, the phase shift between the total voltage and current became -23.2 degree, which means the circuit is **inductive.** (See figure:)

- **Doubling the inductor:**

When doubling the value of the inductor, by connecting another inductor in series with the original one, the phase shift became -43.6 degree, the circuit become **less inductive.** (See figure:)



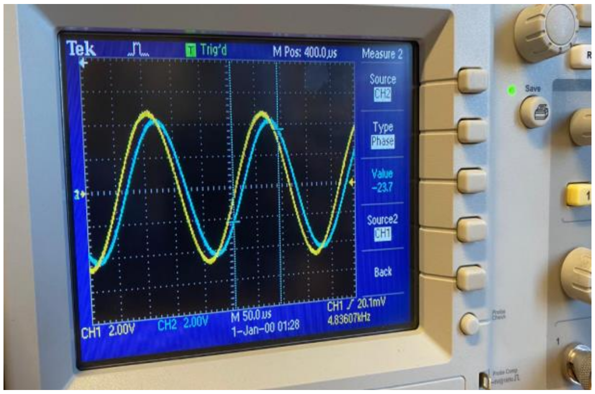


Figure 28: Doubling Capacitor

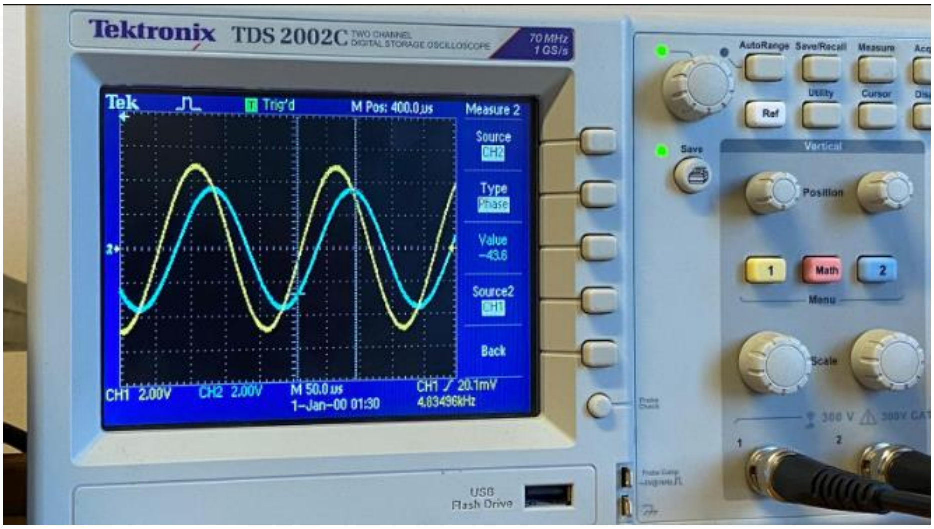


Figure 29: Doubling Resistor

Theoretical Results:

To find the phase shift among different values of frequencies, we have to find the reactance part, and apply the following:

$$X = \boldsymbol{Xl - Xc = 2\pi f L - \frac{1}{2\pi f C}, \theta = tan^{-1}\left(\frac{Xl - Xc}{R}\right) = tan^{-1}\left(\frac{X}{R}\right)}$$

1. **Frequency=1000Hz:**

   Calculating the reactance:

   $$X = 2\pi f L - \frac{1}{2\pi f C} = 62.8 - 1592.35 = -1529.5\ ohm.$$

   Then the phase shift:

   $$\theta = \tan^{-1}\left(\frac{X}{R}\right) = \tan^{-1}\left(\frac{-1529.5}{330}\right) = -77.8\ degree$$

2. **Frequency=2000Hz:**

   Calculating the reactance:

   $$X = 2\pi f L - \frac{1}{2\pi f C} = 125.6 - 796.1 = -670.5\ \ ohm.$$

   Then the phase shift:

$$\theta = \tan^{-1}\left(\frac{X}{R}\right) = \tan^{-1}\left(\frac{-670.5}{330}\right) = -63.7\ degree$$

3. **Frequency=4000Hz:**

Calculating the reactance:

$$X = 2\pi f L - \frac{1}{2\pi f C} = 251.2 - 398.08 = -146.889\ ohm.$$

Then the phase shift:

$$\theta = \tan^{-1}\left(\frac{X}{R}\right) = \tan^{-1}\left(\frac{-146.889}{330}\right) = -23.99\ degree$$

4. **Frequency=6000Hz:**

Calculating the reactance:

$$X = 2\pi f L - \frac{1}{2\pi f C} = 376.8 - 265.39 = 111.4\ ohm.$$

Then the phase shift:

$$\theta = \tan^{-1}\left(\frac{X}{R}\right) = \tan^{-1}\left(\frac{111.4}{330}\right) = 18.65\ degree$$

5. **Frequency=8000Hz:**

Calculating the reactance:

$$X = 2\pi f L - \frac{1}{2\pi f C} = 502.4 - 19.904 = 482.49\ ohm.$$

Then the phase shift:

$$\theta = \tan^{-1}\left(\frac{X}{R}\right) = \tan^{-1}\left(\frac{482.49}{330}\right) = 55.62\ degree$$

6. **Frequency=fo:**

Calculating the reactance:

$$X = 2\pi f L - \frac{1}{2\pi f C} = 316.07 - 316.38 = -0.313\ ohm.$$

Then the phase shift:

$$\theta = \tan^{-1}\left(\frac{X}{R}\right) = \tan^{-1}\left(\frac{-0.313}{330}\right) = -0.054\ degree$$

As shown in the following table, it is noticed that the results of both experimental and theoretical calculations are so close which leads us to know that the results are true.

Table 9: Comparison between experimental the theoretical results in the RLC circuit.

Freq (Hz)	1000	2000	4000	6000	8000	fo
Experimental	*-77.3 deg*	*-60.3 deg*	*-20.7deg*	*21.1 deg*	*44.7 deg*	*0.0 deg*
Theoretical	$-77.8\ deg$	$-63.7\ deg$	$-23.99\ deg$	$18.65\ deg$	$55.62\ deg$	$-0.054\ deg$

3. Sinusoidal steady state power:

In this part, the following circuit was connected on the board with 1 Vrms and 2000 Hz frequency. As shown below:

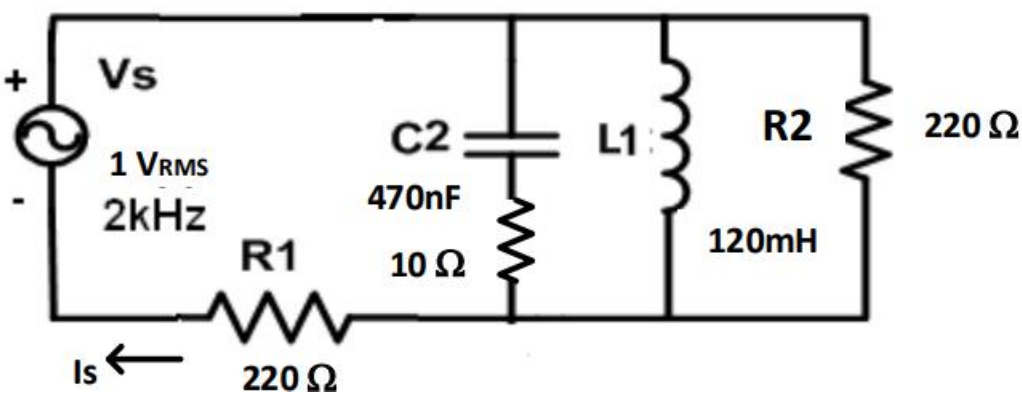


Figure 30: RLC Circuit

From the practical results, the values of the rms voltage and current are the following:

The values of **Vs=1 Volt** and **Is= 3.062 mA**.
Then Rrms = 1/3.062 = 0.326 Kohm

Table 10:RLC Circuit experimental results

V_{R1}	$V_L = V_{R2}$	I_L	I_{R2}	V_S	I_S	($\Theta Vs-\Theta Is$)	V_C	I_C	($\Theta Vc-\Theta Ic$)
0.702	0.417	0.269	1.837	1	3.062	21.4	0.417	2.2587	20.7

1. Computing the active power (Average power, reactive power, and power factor):

- To calculate the values of active power:

$$P_{avg} = V_{rms} I_{rms} \cos(\theta)$$

1. For R1 $= \mathbf{1}.00 * 3.062 * \boldsymbol{co}(20.7) = 2.86\boldsymbol{mWatt}$.
2. For R2 $= 0.417 * 1.837 * \boldsymbol{co}(20.7) = 0.73\boldsymbol{mWatt}$.

Note: The average power of the capacitor and inductor is zero.

Note: I have forgot to take the data of the voltage across Rx.

- To calculate the values of reactive power:

$$P_{avg} = V_{rms} I_{rms} \sin(\theta)$$

$$For\ C = 0.417 * 2.2587 * \boldsymbol{si}(20.7) = 0.333\boldsymbol{mWatt}.$$
$$For\ L = 0.417 * 0.269 * \boldsymbol{si}(20.7) = 0.04\boldsymbol{mWatt}.$$

- To calculate the values of power factor:

$$P_{factor} = \cos(\theta) = \cos(-39.9) = 0.767$$

Conclusion

This experiment has covered many concepts such as determining the impedance for different types of AC circuits, the current, and the voltage for the elements in the specified circuits. The capacitive and inductive behavior was examined. We saw how the current leads and lags the voltages in different types of circuit. Besides that, power of the sinusoidal steady-state circuits was calculated.

References

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[6] https://www.electronics-tutorials.ws/accircuits/power-in-ac-circuits.html
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Accessed on 29/4/2023 5:06pm

ENEE2103 Lab Manual.

Appendix

Circuits & Electronics Lab ENEE2103

Table 4.1

ما ضيا 2Cursors

f [Hz]	Vrms	Irms	Δt	Phase shift
500	3.381	1.06	0	0
1k	3.381	1.06	0	0
1.5k	3.381	1.06	0	0

No delay neither lag!

Table 4.2

f [Hz]	Vrms	Irms	Δt	Phase shift
500	3.628	0.835	–	42.9
1k	3.614	0.9357	90 μs	24.1
1.5k	3.610	1.078	–	17.7

$\frac{2\pi}{\Delta t}$

phase shift curser ?.

Table 4.3

f [Hz]	Vrms	Irms	Δt	Phase shift
500	3.574	2.032	–	+32.7
1k	3.614	1.506	170	+51.5
1.5k	3.634	1.135	–	62.8

Table 4.4

f	1k	2k	4k	6k	8k	fo =4,847
Δt	250 μs	88 μs	.19 μs	14 μs	17.6	0
$(\Theta_{Vs}-\Theta_{Is})$	77.3	60.3	20.7	21.1	44.7	0

Table 4.5

$V_{(R1)}$	$V_L=V_{(R2)}$	I_L	I_{R2}	V_s	I_s	$(\Theta_{Vs}-\Theta_{Is})$	V_c	I_c	$(\Theta_{Vc}-\Theta_{Ic})$
0.702	0.417	0.269	1.817	~~2.1~~ 1	3.092	21.4	0.417	2.587	20.7

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