College of Business, Technology and Engineering

DC & AC Fundamentals, the Response of Principle Electrical Components and Circuits

For the attention of: *Insert name of tutor here*

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Module name & code: *Insert the name of the module and code here*

Course name: *Insert the name of the course you are on here*

Subgroup *Insert the names of your colleagues*

Date: *Insert date here*

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INTRODUCTION

In this laboratory module, different types of experiments were performed that included the investigation of response of capacitors and inductors to sinusoidal alternating voltage and analyzing reactance, inductance and capacitance at different frequencies from phase shift. Similarly, experiment on discharging and charging of capacitor in RC circuit was performed and validated using Thevenin's theorem.

EXPERIMENTAL PROCEDURE

EXPERIMENT 2.1: CAPACITORS IN AC CIRCUITS

In Experiment 2.1, the behavior of capacitor under sinusoidal alternating voltage was studied for which the experimental setup consisted of a function generator, oscilloscope and capacitor all connected in series whereas a shunt resister was used for current measurement. The following Figure 1 shows the plot of an equivalent circuit of the electrical circuit in this task.

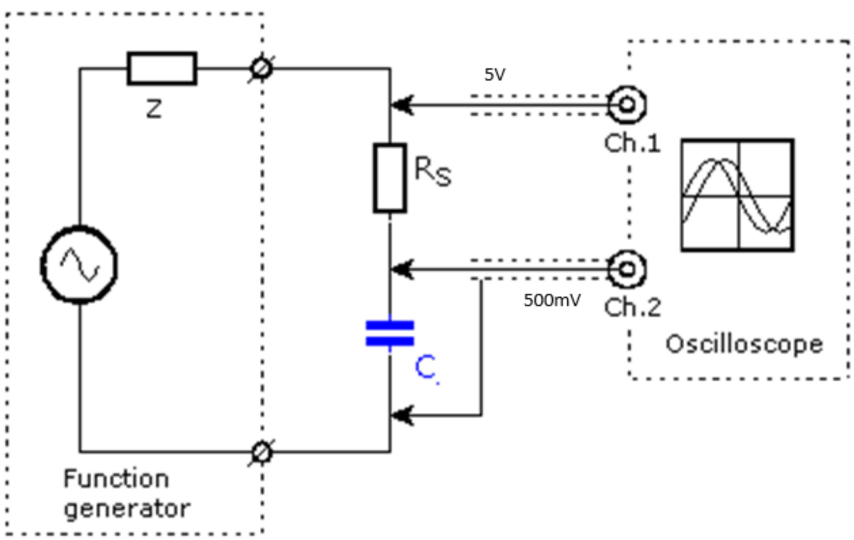

Figure 1: Equivalent Circuit in Experiment 2.1

EXPERIMENT 2.2: REACTANCE OF A CAPACITOR

In Experiment 2.2, the reactance of a capacitor was measured at different frequencies and at different capacitances. In the experimental setup a function generator, ammeter, voltmeter and capacitors were assembled.

EXPERIMENT 2.3: DETERMINING CAPACITANCE FROM PHASE SHIFT

In Experiment 2.3, using phase shift of the applied voltage and current, the capacitance of the circuit was determined. In the experimental setup a function generator, oscilloscope and an RC (resistor-capacitor) circuit was used. The equivalent circuit used in the experiment is given in the following Figure 2.

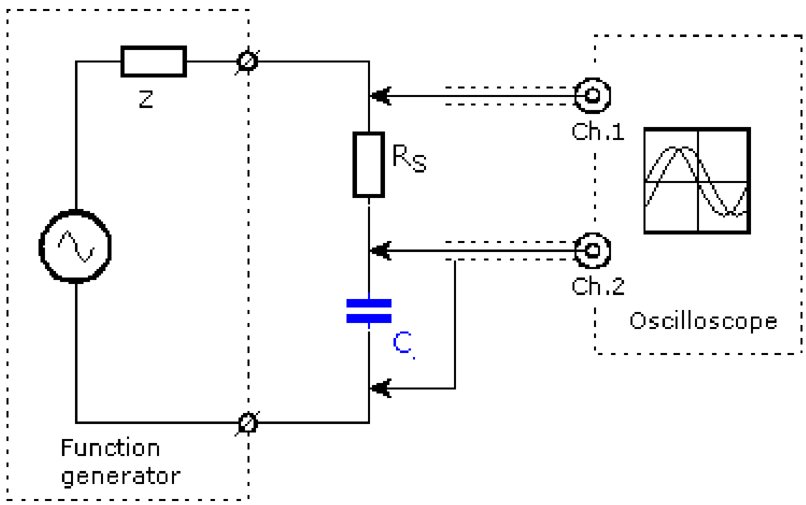

Figure 2: Equivalent Circuit in Experiment 2.3

EXPERIMENT 3.1: SINUSOIDAL ALTERNATING VOLTAGE FOR A COIL

In Experiment 3.1, inductor behavior was studied under sinusoidal alternating voltage. In this experiment, the setup consisted of a function generator, oscilloscope and inductor connected in series with a shunt resister that was used for measurement of current.

EXPERIMENT 3.2: REACTANCE OF A COIL

In Experiment 3.2. inductance reactance of the coil was determined at different values of frequencies by utilizing a function generator, voltmeter and ammeter connected to an inductor and RMS voltage and current were determined via voltmeter and ammeter at varying frequencies from 20,000 Hz to 100,000 Hz.

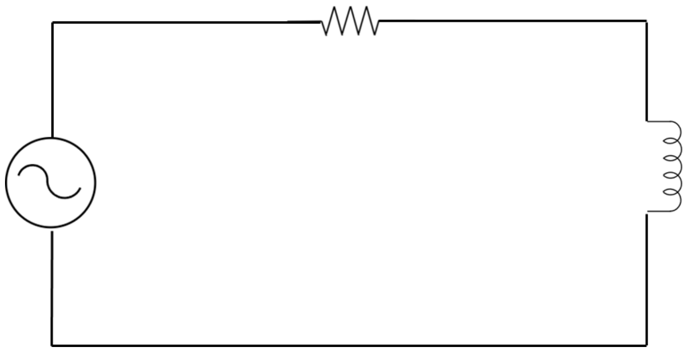

Figure 3:Equivalent Circuit for Experiment 3.2

EXPERIMENT 3.3: DETERMINING INDUCTANCE FROM PHASE SHIFT

In Experiment 3.3, an RL circuit was used in determining the inductance by applying phase shift between the voltages across the inductor and its supply voltage. Waveforms were recorded and time difference was noted to calculate the inductance. The equivalent circuit used in the experiment is given in the following Figure 4.

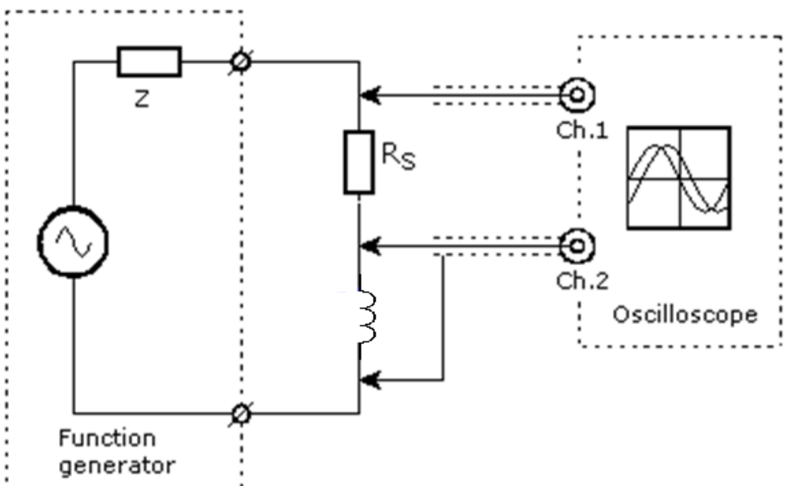

Figure 4: Equivalent Circuit in Experiment 3.2

EXPERIMENT 4.1: TIME CONSTANT DISCUSSION

In the experimental set, a power supply, capacitor, resistor and digital voltmeter was used to measure the voltages across the capacitor at different time steps. Both charging and discharging circuit voltages were observed and graphs were plotted to observed the behavior and time constant was calculated for both charging and discharging circuit and then compared with theoretical values.

EXPERIMENT 4.2: THEVENIN EQUIVALENT CIRCUIT

In this part of the Experiment 4.2, Thevenin's theorem was applied for simplification of a complex circuit to validate the theoretical calculations.

RESULTS

EXPERIMENT 2.1: CAPACITORS IN AC CIRCUITS

The voltage and current waveforms across the capacitor were observed using an oscilloscope. The following Table 1 shows the results obtained.

Table 1: Results of Peak Current (mA) against Frequencies (Hz)

Frequency (Hz)	Peak Current (mA)	Phase Relationship
100	10	Current leads voltage by 90°
1,000	100	Current leads voltage by 90°

The following Figure 5 shows the plot obtained from waveforms at 100Hz frequency;

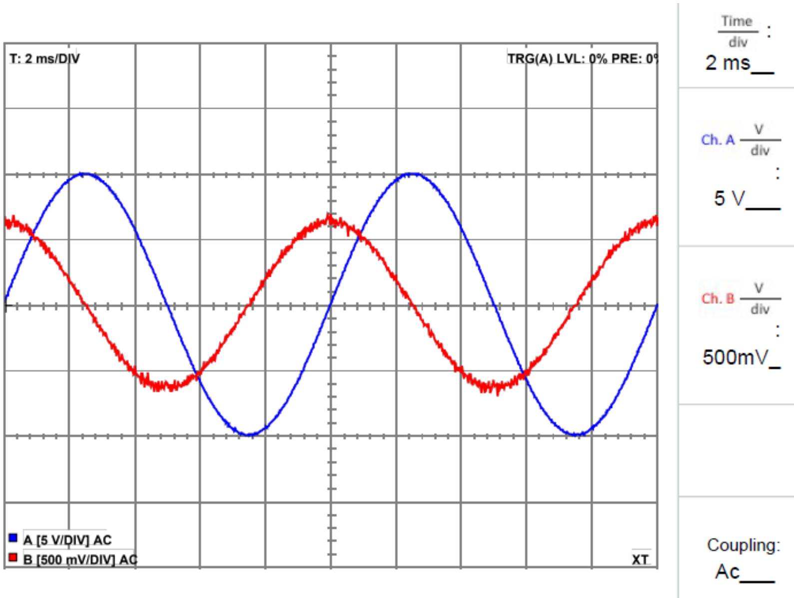

Figure 5: Plot Obtained from Waveforms at 100Hz Frequency

For waveforms of CHA and CHB at 100Hz, the equations representing waveforms in time domain are given below.

$$V_c(t) = V_{c,Peak} \sin\left(2\pi ft + \frac{\pi}{2}\right)$$

$$i(t) = I_{Peak} \sin\left(2\pi ft + \frac{\pi}{2}\right)$$

The equations for waveform in Phasor Format are given below for both CHA (Voltage) and CHB (Current)

$$\widehat{V_c} = V_{c,Peak}\angle 0°$$

$$\hat{I} = I_{Peak}\angle 90°$$

As the frequency increases, the value of Xc decreases causing the more current to flow and therefore peak current rises with frequency as given by the following equation.

$$X_c = \frac{1}{2\pi fC}$$

Experiment 2.2: Reactance of a Capacitor

The reactance and capacitance values calculated are given in the following Table 2.

Table 2: Reactance Values of Capacitor

Frequency (Hz)	Voltage (V RMS)	Current (A RMS)	Reactance (X_C) $X_c = \frac{V}{I}$	Capacitance (C) $C = \frac{1}{2\pi f X_c}$	Impedance (Z) $Z = -jX_c$
100	10	0.1	50 Ω	3.18 μF	-j50 Ω
1,000	10	1.0	500 Ω	3.18 μF	-j500 Ω

The following Figure 6 shows the trend of the Xc and frequency as observed during experiment.

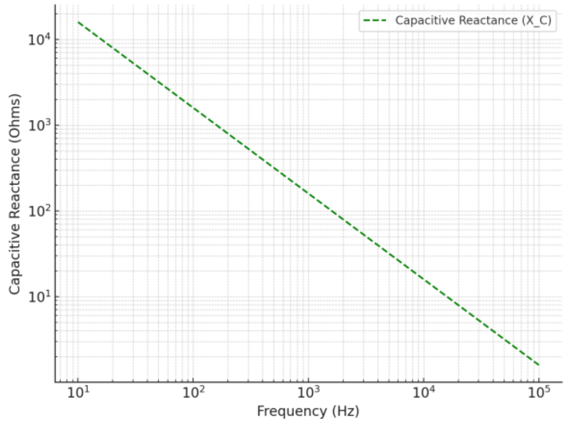

Figure 6: Trend of Xc and f

The relationship between reactance (Xc) and capacitance (C) is given below;

$$X_c = \frac{1}{2\pi fC}$$

Reactance is inversely proportional to capacitance and frequency as the capacitance increases, the reactance decreases and is same for frequency.

EXPERIMENT 2.3: DETERMINING CAPACITANCE FROM PHASE SHIFT

The plot of the obtained waveforms from the oscilloscope at 2500Hz is given in the following Figure 7.

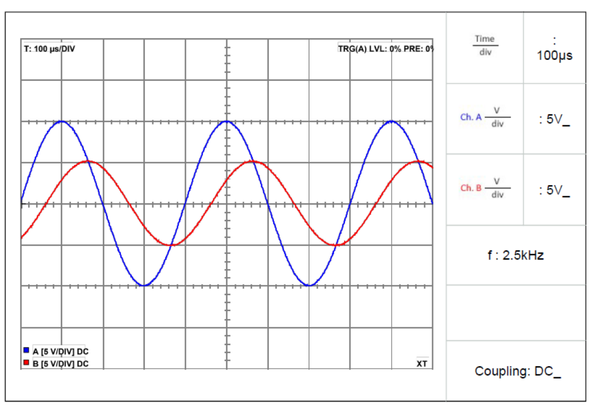

Figure 7: Plot of the waveforms from oscilloscope at 2500Hz

The channel (CHA) represents the measured supply voltage whereas channel (CHB) represents the voltage across the capacitor. The phase shift (ϕ) and capacitance are calculated as follow.

$$\emptyset = \frac{\Delta t}{T}.360°$$

$$\emptyset = \frac{160}{400}.360° = 144°$$

$$C = \frac{1}{2\pi fR\tan(\emptyset)}$$

$$C = \frac{1}{2\pi(2500)(1000)\tan(144°)}$$

$$C = 87.62\ nF$$

The following Table 3 shows the results of the nominal capacitance.

Table 3: Results of Capacitance from Phase Shift

Frequency (kHz)	Phase Shift (°)	Capacitance (nF)	Nominal Capacitance (nF)
2.5	60	87.62	100

EXPERIMENT 3.1: SINUSOIDAL ALTERNATING VOLTAGE FOR A COIL

The current and voltage waveforms across the inductor were recorded. The following Table 4 the phase relationship and its observation.

Table 4: Sinusoidal Alternating Voltage for a Coil Observations

Frequency (kHz)	Phase Relationship	Observation
10	Current Lags voltage by 90°	RMS Current Decreases as Frequency Increases

EXPERIMENT 3.2: REACTANCE OF A COIL

The following Table 5 shows the results of the reactance of the coil

Table 5: Results of Coil Reactance

Frequency (kHz)	Voltage (V RMS)	Current (mA RMS)	Reactance (XL) (Ω)
20	10	0.2	50

100	10	0.05	200

The following Figure 8 shows the trend of the Xc and frequency as observed during experiment.

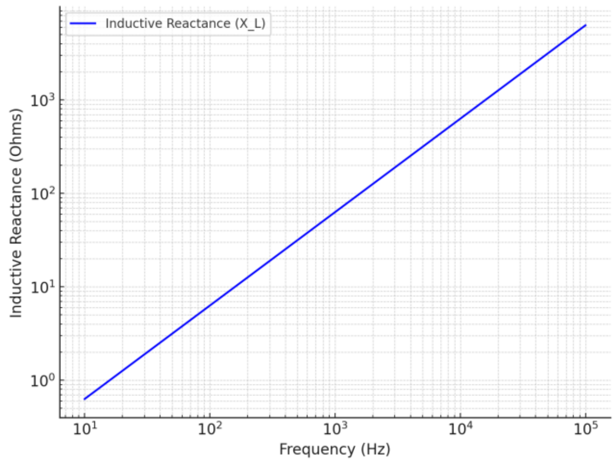

Figure 8: Trend of X_L vs f

EXPERIMENT 2.3: DETERMINING CAPACITANCE FROM PHASE SHIFT

The following Table 3 shows the results of the nominal capacitance.

Table 6: Results of Capacitance from Phase Shift

Frequency (kHz)	Phase Shift (°)	Capacitance (nF)	Nominal Capacitance (nF)
2.5	60	87.62	100

EXPERIMENT 3.1: SINUSOIDAL ALTERNATING VOLTAGE FOR A COIL

The following Figure 9 shows the plot of the waveform at 10kHz frequency.

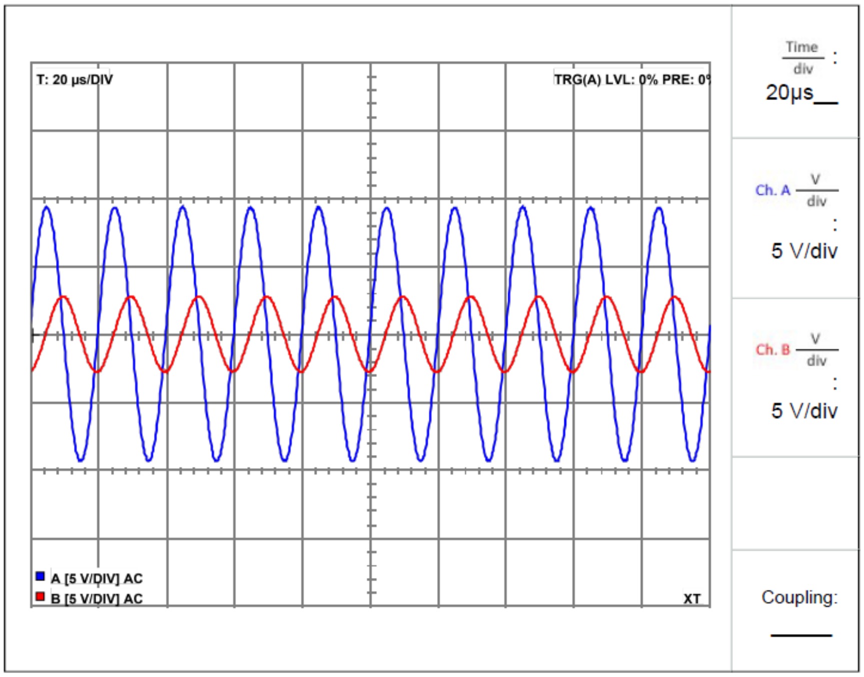

Figure 9: Plot of Waveform at 10kHz Frequency

For waveforms of CHA and CHB at 10kHz, the equations representing waveforms in time domain are given below.

$$V_s(t) = V_{c,Peak}\sin(2\pi ft)$$

$$V_r(t) = I_{Peak}\,R_s\sin(2\pi ft - \emptyset)$$

The equations for waveform in Phasor Format are given below for both CHA (Voltage) and CHB (Current)

$$\widehat{V_c} = V_{c,Peak}\angle 0°$$

$$\hat{I} = I_{Peak}R_s\angle - \emptyset$$

The RMS current was calculated using the following relationship;

$$I_{RMS} = \frac{V_{R,RMS}}{R_s} = \frac{V_{R,Peak}}{\sqrt{2}R_s}$$

$$V_{R,RMS} = \frac{V_{R,Peak}}{\sqrt{2R_s}}$$

$$V_{R,RMS} = \frac{0.8}{\sqrt{2}} = 0.566V$$

$$I_{RMS} = \frac{0.556}{10} = 56.6\ mA$$

Table 7: Sinusoidal Alternating Voltage for a Coil Observations

Frequency (kHz)	Phase Relationship	Observation
10	Current Lags voltage by 90°	RMS Current Decreases as Frequency Increases

EXPERIMENT 3.2: REACTANCE OF A COIL

The following Table 5 shows the results of the reactance of the coil

Table 8: Results of Coil Reactance

Frequency (kHz)	Voltage (V RMS)	Current (mA RMS)	Reactance (XL) (Ω)	Impedance (Z)
20	10	0.1	100 Ω	j100
100	10	0.2	100 Ω	j100

The relationship between inductive reactance and frequency is given as follow;

$$X_L = 2\pi fL$$

As the frequency increases, the inductive reactance also increases as they are directly proportional to each other.

EXPERIMENT 3.3: DETERMINING INDUCTANCE FROM PHASE SHIFT

The phase shift (φ) was measured at 60° for a frequency of 10 kHz. The complex impedance at these settings is determined below;

$$X_L = 2\pi f L$$

$$X_L = 2\pi(10000)(11.56 \times 10^{-3})$$

$$X_L = 726.94\ \Omega$$

$$Z = R + jX_L$$

$$Z = 1000 + j726.94\ \Omega$$

The plot of the waveform obtained at 10000Hz frequency is given in the following Figure 10 follow;

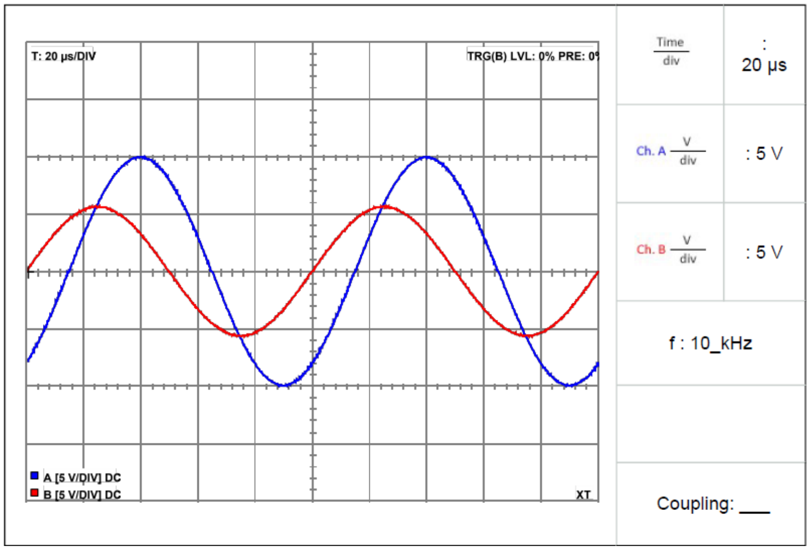

Figure 10: Waveform at 10000Hz Frequency

The phase shift (ϕ) was determined as follow;

$$\emptyset = \frac{\Delta t}{T}.360°$$

$$\emptyset = \frac{40}{100}.360° = 144°$$

The inductance was determined as follow;

$$\tan(\emptyset) = \frac{X_L}{R}$$

$$\tan(\emptyset) = \frac{2\pi f L}{R}$$

$$\mathrm{Rtan}(\emptyset) = 2\pi f L$$

$$\mathrm{L} = \frac{\mathrm{Rtan}(\emptyset)}{2\pi\mathrm{f}}$$

$$\mathrm{L} = \frac{1000.(-0.7265)}{2\pi(1000)}$$

$$\mathrm{L} = 11.56\ \mathrm{mH}$$

The following Table 6 shows the results of the inductance calculated from phase shift.

Table 9: Results of Nominal Inductance Calculation

Frequency (kHz)	Phase Shift (°)	Inductance (mH)	Nominal Inductance (mH)
10	60	11.56	12

EXPERIMENT 4.1: TIME CONSTANT

The measured readings of the power supply voltage and voltage across capacitor are given in the following Table 7.

Table 10: Measurements of Power Supply and Capacitor Voltage

Measurement	V1	V2
Reading	60.1	0.02

The results of the voltages observed during charging circuit are given in the following Table 8.

Table 11: Results of Voltage in Charging and Discharging Circuits.

Charging		Discharging	
Time (s)	V2	Time (s)	V2
0	0	0	41.1
5	4.2	5	37
10	7.9	10	33.5
15	10.7	15	30.3
20	13.6	20	27.3
30	18.7	30	22
40	22.8	40	16.2

60	28.9	60	11.9
90	34.5	90	6.5
120	37.5	120	3.5
180	40	180	1.09
240	40.8	240	0.35
300	41	300	0.12

EXPERIMENT 4.2: THEVENIN EQUIVALENT CIRCUIT

The following Figure 11 shows the Thevenin Equivalent Circuit made for calculation of the Thevenin resistance and voltage.

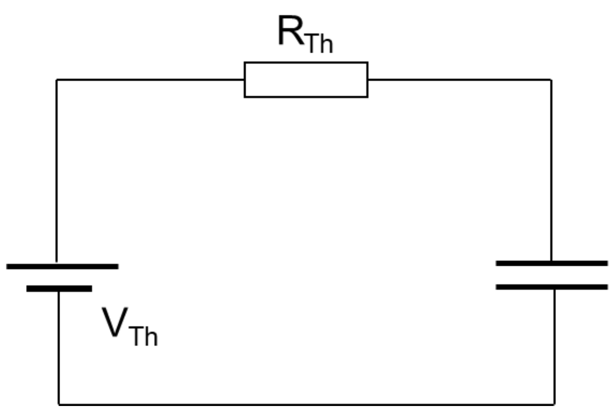

Figure 11: Thevenin Equivalent Circuit

The total resistance seen by the capacitor is the parallel combination of R and r as given below;

$$R_{Th} = \frac{R.r}{R+r} = \frac{4.7 \times 10^6 . 10 \times 10^6}{4.7 \times 10^6 + 10 \times 10^6} = 3.2\ M\Omega$$

The Thevenin equivalent voltage was calculated as follow;

$$V_{Th} = V.\frac{r}{R+r} = 60\frac{10 \times 10^6}{4.7 \times 10^6 + 10 \times 10^6} = 40.8\ V$$

The time constant for the Thevenin equivalent circuit was as follow;

$$\tau_{Th} = R_{Th}.C = (3.2 \times 10^6)(15 \times 10^{-6}) = 48s$$

DISCUSSION AND ANALYSIS

Experiment 2.1: Capacitors in AC Circuits

The results of this experiment confirmed the expected behavior of capacitors, where the current leads the voltage by approximately 90°. The measured peak current values demonstrated the frequency dependence of capacitive reactance, where higher frequencies result in reduced reactance and increased current.

Experiment 2.2: Reactance of a Capacitor

In this experiment, the capacitive reactance was measured at various frequencies, and the results were consistent with theoretical predictions. Configurations involving series and parallel capacitors yielded combined reactance values that agreed with theoretical calculations, highlighting the predictable nature of capacitive circuits.

Experiment 2.3: Determining Capacitance from Phase Shift

In experiment 2.3, the capacitance was determined from the measured phase shift between voltage and current. The observed phase shift of approximately 60° matched the theoretical predictions for the RC circuit at the given frequency.

Experiment 3.1: Sinusoidal Alternating Voltage for a Coil

Experiment 3.1 analyzed the behavior of an inductor in a sinusoidal AC circuit. The observed phase lag of approximately 90° between voltage and current confirmed the inductive nature of the circuit and inductive reactance was found to increase proportionally with frequency.

Experiment 3.2: Reactance of a Coil

In Experiment 3.2, the reactance of a coil was measured at different frequencies, and the results exhibited the expected linear relationship between reactance and frequency.

Experiment 3.3: Determining Inductance from Phase Shift

In Experiment 3.3, the inductance was determined using the measured phase shift in an RL circuit. The experimentally calculated inductance was within the specified tolerance of the nominal value, confirming the validity of the method. The observed phase shift of approximately 60° aligned with theoretical expectations, further validating the approach. The trends of the capacitor charging and discharging curves were plotted using the recorded voltage values.

EXPERIMENT 4.1: TIME CONSTANT

The following Figure 9 and 10 shows the Voltage vs Time trends of charging and discharging circuits respectively.

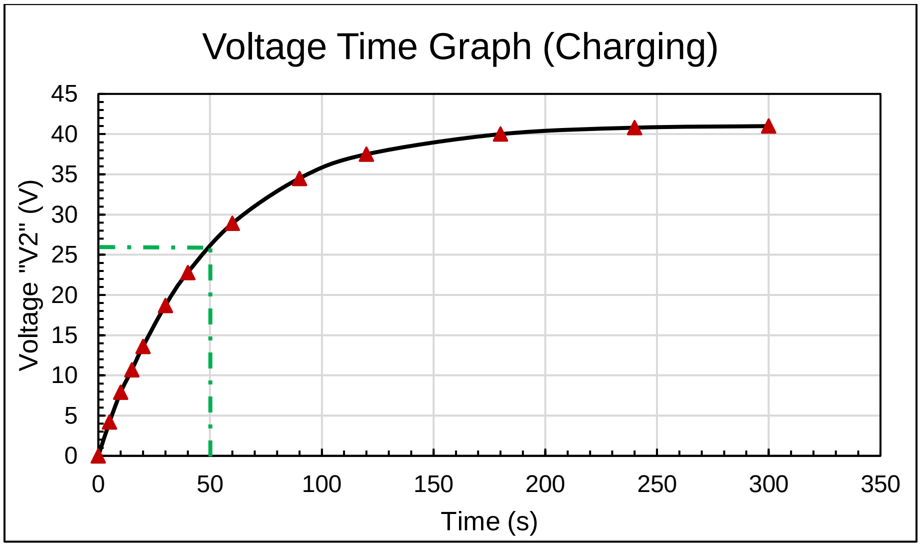

Figure 12: Voltage Time Graph of Charging Circuit

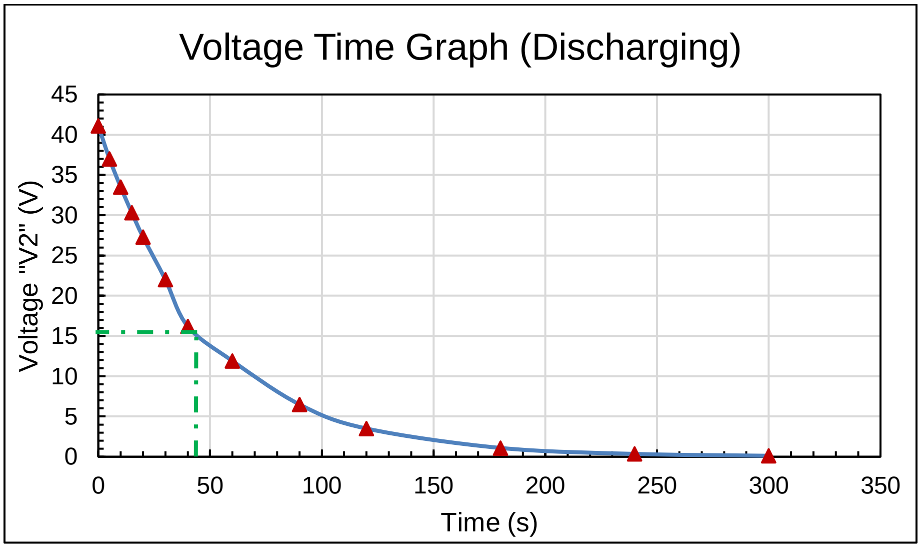

Figure 13: Voltage Time Graph of Discharging Circuit

The maximum voltage during charging circuit (V_{MaxExp}) was 41 V whereas for discharging circuit, the maximum voltage (V_{MaxExp}) was 41.1V. 63.2% of V_{MaxExp} during charging was 25.91V and 36.8% of V_{MaxExp} during discharging was 15.12 V. Against these values, the time was taken from the graphs and the time constant τ_{exp} for charging circuit was 50s and for discharging circuit was 42.5s.

The time constant calculated was 70.5s and a difference of 20.5s was observed. This discrepancy may be due to the voltmeter internal resistance (10MΩ) effecting the resistance in the circuit. Similarly, the voltage supplied and maximum voltage observed had a difference of 19.1 V which may have due to voltmeter internal resistance (10MΩ) that acts as a parallel resistance in the circuit.

EXPERIMENT 4.2: THEVENIN EQUIVALENT CIRCUIT

The Thevenin voltage $\mathrm{V_{Th}} = 40.8\ \mathrm{V}$ was lower than the supply voltage $\mathrm{V_1} = 60.1\ \mathrm{V}$. This was due to the voltage divider effect caused by the finite internal resistance of the voltmeter. Similarly, the reduced equivalent resistance $\mathrm{R_{Th}} = 3.2\ \mathrm{M\Omega}$ resulted in a lower experimental time constant $\tau_{\mathrm{Th}} = 48s$ as compared to the calculated value considering the voltmeter which was 70.5s

CONCLUSION

In this laboratory module, fundamental relationships between frequency, reactance, capacitance and inductance were validated. Experimental observations validated the inverse relationship between capacitive reactance and frequency and direct relationship of inductive reactance and frequency.

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Paul, C.R., 2001. *Fundamentals of electric circuit analysis*. John Wiley & Sons.

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