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Lab 2

RC Circuit Phase Shift

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Contents

Chapter 1

Overview

1.1 Objective

This report details the analytical and simulation-based investigation of two circuits. The first involves calculating the value of a resistor (R_1) such that the voltage across a given resistor (R_3) in a resistive network is 3.8V. The second part explores the behavior of an RC circuit, focusing on the phase shift between input and output voltages as the frequency varies. Simulations were performed to verify theoretical predictions and compare results across different frequencies.

1.2 Equipment

- Breadboard
- Oscilloscope
- Function Generator
- Power Supply
- Multimeter
- Resistors (150Ω, 220Ω, 330Ω, $2 \times 1k\Omega$, $2.2k\Omega$, $3.3k\Omega$)
- Capacitor ($1\mu F$)

Chapter 2

Procedure

2.1 Resistor Network Calculation

2.1.1 Theoretical Analysis

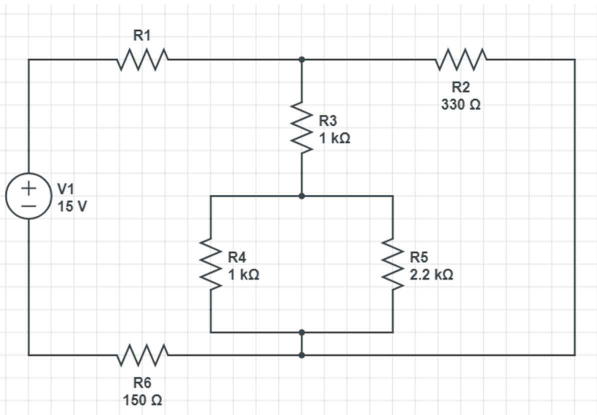

Figure 2.1: Resistor Network

To find the R_1 value, we can divide total voltage to total current and find the equivalent resistance. Then we can find the R_1 value by using the equivalent resistance:

$$\frac{V_{total}}{I_{total}} = R_{eq}$$
$$I_{total} = I_1 + I_2$$
$$I_2 = \frac{3.8}{1k} = 3.8 \times 10^{-3} A$$
$$I_1 = \frac{R_{345}}{R_2} \times I_2 = \frac{1687.5}{330} \times 3.8 \times 10^{-3} A$$
$$I_{total} = \frac{5111}{2.2 \times 10^5} A$$

$$
\begin{aligned}
R_{eq} &= \frac{15}{\frac{5111}{2.2\times10^5}}\Omega \\
&= \frac{3.3\times10^6}{5111}\Omega \\
R_1 + 150 + \frac{1687.5\times330}{1687.5+330} &= \frac{3.3\times10^6}{5111}\Omega \\
\implies R_1 &\approx 219.644\Omega
\end{aligned}
$$

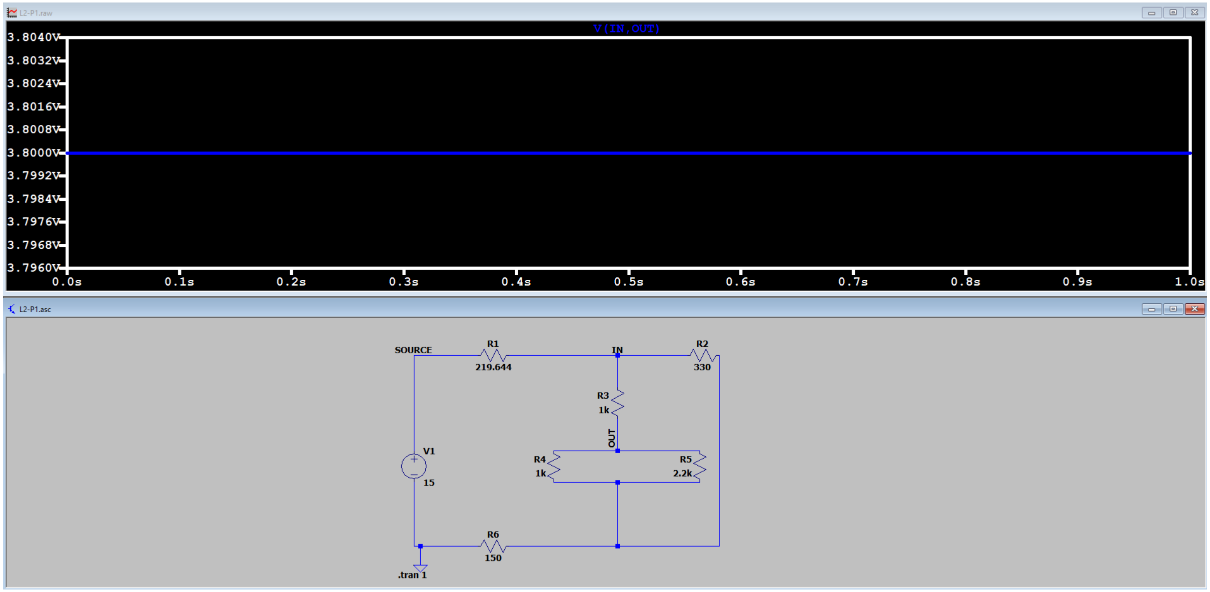

Figure 2.2: 219.644Ω Resistor Result

After calculations, R_1 value is found as 219.644Ω. The simulation results are matching with the calculated results. The voltage on the R_3 resistor is $3.8V$ as expected.

Resistor	**Voltage**	**Current**
R_1	5.1027V	23.2318mA
R_2	6.4124V	19.4318mA
R_3	3.7999V	3.7999mA
R_4	2.6124V	2.6124mA
R_5	2.6124V	1.1874mA
R_6	3.4847V	23.2318mA

Table 2.1: Voltage/Current over Resistors

2.1.2 Experimental Analysis

In order to verify our results, we built the circuit in Figure 2.1 and measured the voltage values:

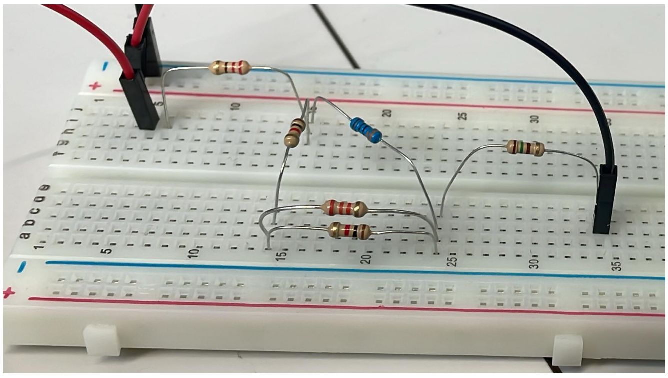

Figure 2.3: Circuit Setup

Figure 2.4: V_{R_1}

Figure 2.5: V_{R_2}

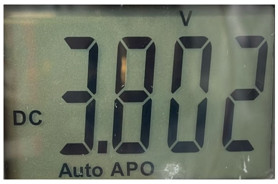

Figure 2.6: V_{R_3}

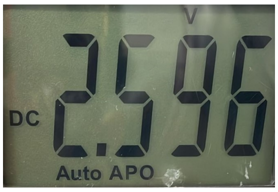

Figure 2.7: V_{R_4}

Figure 2.8: V_{R_5}

Figure 2.9: V_{R_6}

Resistor	Theoretical Result	Experimental Result
R_1	5.1027V	5.13V
R_2	6.4124V	6.38V
R_3	3.7999V	3.8V
R_4	2.6124V	2.59V
R_5	2.6124V	2.59V
R_6	3.4847V	3.43V

Table 2.2: Voltage over Resistors

The experimental results are matching with the theoretical results. The voltage on the R_3 resistor is $3.8V$ as expected.

2.2 RC Circuit Phase Shift Analysis

2.2.1 Theoretical Analysis

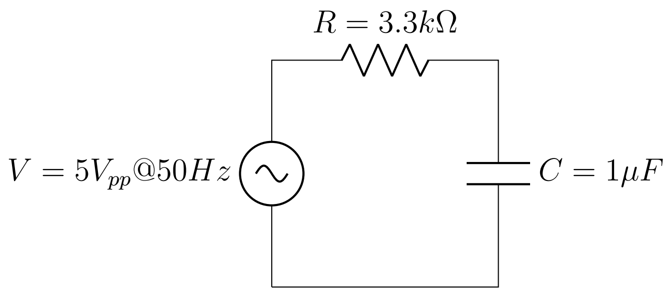

Figure 2.10: Simple RC Circuit

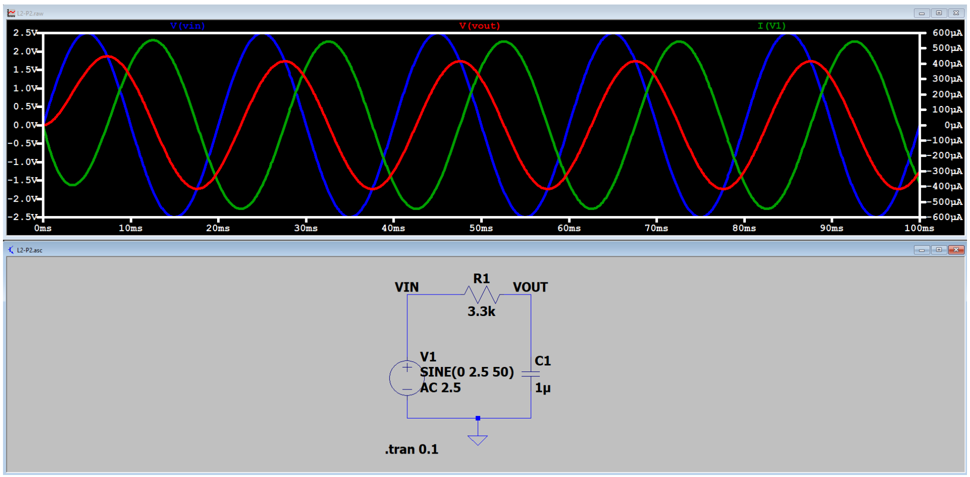

Figure 2.11: RC Circuit Graph

In order to find the phase shift of the RC circuit, we need to find the impedance of the resistor and capacitor. The impedance of the resistor is R and the impedance of the capacitor is $\frac{1}{j\omega C}$. The total impedance of the circuit is the sum of the impedance of the resistor and the impedance of the capacitor. The phase shift of the circuit is $\phi_{Z_{eq}} - 90°$(phase angle of sin):

$$Z_R = R$$
$$Z_C = \frac{1}{j\omega C}$$
$$Z_{total} = Z_R + Z_C = R + \frac{1}{j\omega C} = R + \frac{1}{j2\pi f C}$$
$$\phi = \arctan\left(\frac{\Im(Z_{total})}{\Re(Z_{total})}\right) = \arctan\left(\frac{\frac{1}{2\pi f C}}{R}\right)$$
$$\boxed{\phi = \arctan\left(\frac{1}{2\pi f RC}\right)}$$

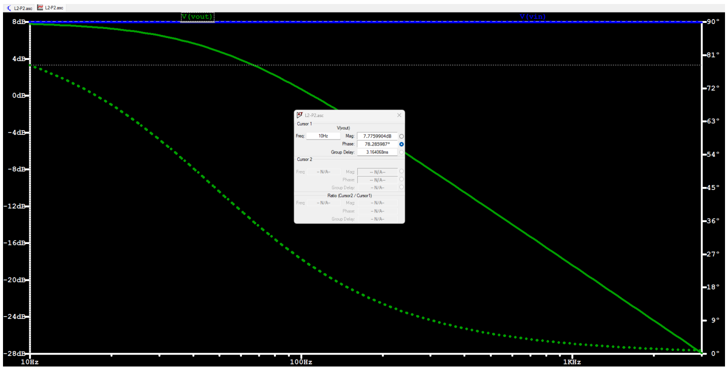

Figure 2.12: $10Hz$ Phase Output

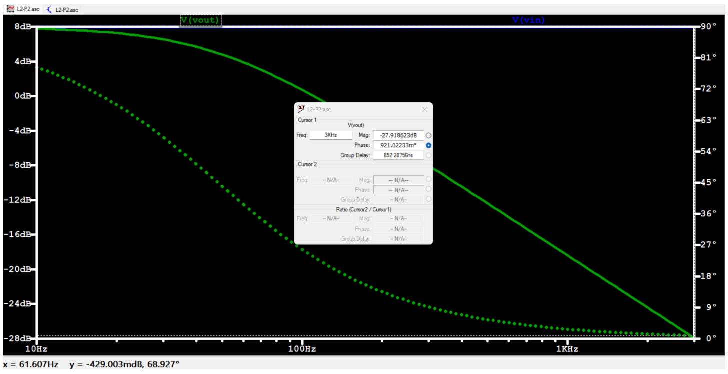

Figure 2.13: $3kHz$ Phase Output

Frequency	**Calculated Phase**	**Simulated Phase**	**Phase Shift**
10Hz	78.2859°	78.285987°	$-11.714013°$
30Hz	58.11°	58.11595°	$-31.88405°$
50Hz	43.96°	43.9667°	$-46.0333°$
100Hz	25.74°	25.747201°	$-64.252799°$
300Hz	9.13°	9.1330658°	$-80.8669342°$
1kHz	2.76°	2.7611528°	$-87.2388472°$
3kHz	$921.02m°$	$921.02233m°$	$-89.078978°$

Table 2.3: Phase Angle Analysis

Calculated and simulated results are matching. The phase angle of the circuit is increasing as the frequency increases. The phase angle of the circuit is almost 90° at $3kHz$. This is expected because at higher frequencies, capacitor can not fully charge and discharge.

2.2.2 Experimental Analysis

In order to verify our results, we built the circuit in Figure 2.10 and measured the phase shift of the circuit.

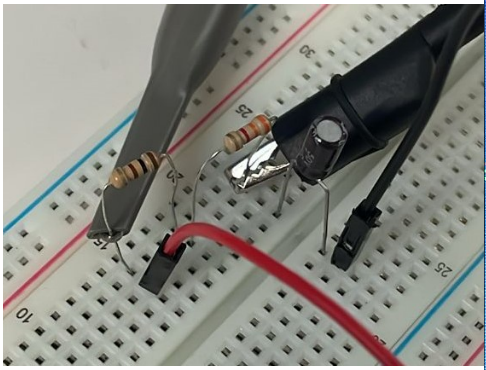

Figure 2.14: Circuit Setup

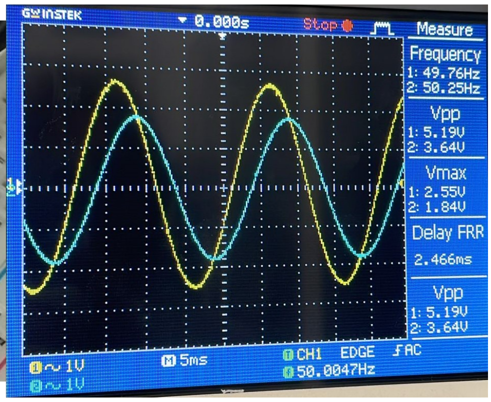

Figure 2.15: 50Hz Graph

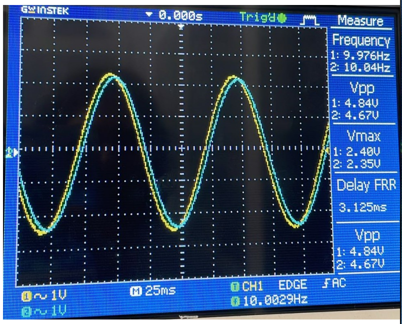

Figure 2.16: 10Hz

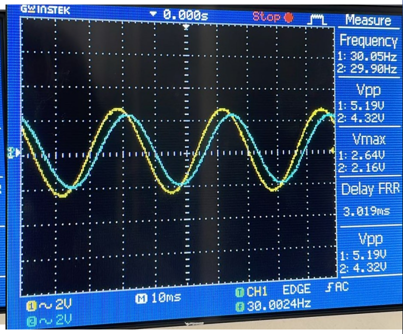

Figure 2.17: 30Hz

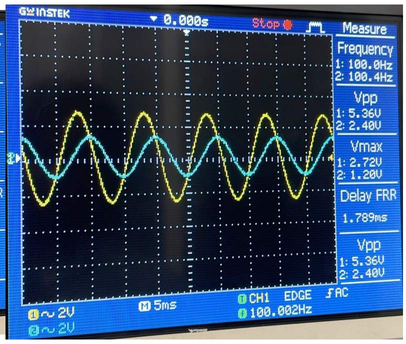

Figure 2.18: 100Hz

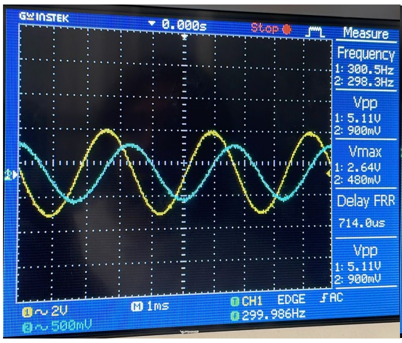

Figure 2.19: 300Hz

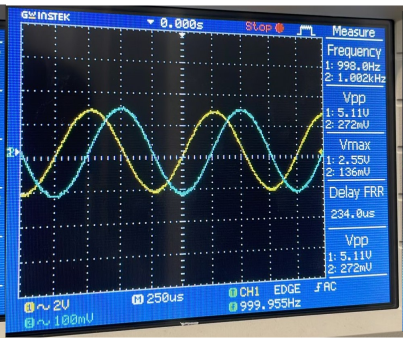

Figure 2.20: 1kHz

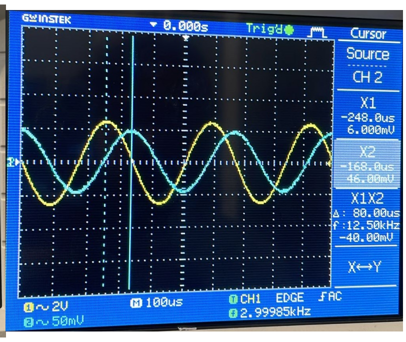

Figure 2.21: 3kHz

Yellow line is the input signal and blue line is the output signal. Used this formula to calculate the phase shift:

$$\phi = 360^\circ \times f \times \Delta t$$

Frequency	**Simulated Shift**	**Measured Δt**	**Measured Shift**
10Hz	$-11.714013°$	3.125ms	$-11.25°$
30Hz	$-31.88405°$	3.019ms	$-32.6052°$
50Hz	$-46.0333°$	2.466ms	$-44.388°$
100Hz	$-64.252799°$	1.789ms	$-64.404°$
300Hz	$-80.8669342°$	$714\mu s$	$-77.112°$
1kHz	$-87.2388472°$	$234\mu s$	$-84.24°$
3kHz	$-89.078978°$	$80\mu s$	$-86.4°$

Table 2.4: Phase Angle Analysis

The calculated and measured results are matching.

Chapter 3

Discussion

- **P1 Observations:** The resistor network's voltage and current distribution were calculated analytically. The calculated value of R_1 ensures that the voltage across R_3 is exactly 3.8V. The simulation closely matched the theoretical values, validating the accuracy of the analytical approach.

- **P2 Observations:**
  - **Low Frequencies:**
    - At lower frequencies, the calculated and simulated phase angles are relatively small, indicating that the circuit is not heavily reactive. The phase angle increases as the frequency rises, which is expected behavior in an RC circuit.
    - For example, at 10 Hz, the phase angle is approximately 11°, while at 100 Hz, it has increased to 64°. This is because, at lower frequencies, the capacitor takes longer to charge and discharge, resulting in a smaller lag between input and output signals.
  - **Mid-Range Frequencies (100Hz-300Hz):**
    - As the frequency continues to increase, the phase angle increases more significantly, reaching value 80° at 300 Hz. The circuit begins to exhibit weaker capacitive behavior, with the output voltage decreasingly lagging behind the input voltage.
  - **High Frequencies (1000Hz-3000Hz):**
    - At higher frequencies, the phase shift approaches a maximum of nearly 90°. The output voltage is almost completely out of phase with the input, signifying that the capacitor now dominates the circuit's impedance.

Chapter 4

Conclusion

This lab effectively demonstrated the use of analytical methods and simulations to analyze both resistive networks and RC circuits. In the resistive network, the desired voltage was achieved through careful calculation and verified by simulation. In the RC circuit, the phase shift behavior was investigated across a range of frequencies, and results aligned with theoretical predictions. These exercises underscored the importance of both manual calculations and simulations in understanding circuit behavior. The combination of theory and simulation tools like LTSpice offers a comprehensive approach to electrical circuit analysis.