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## EXPERIMENT 3

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# Abstract

This report presents a comprehensive analysis of the Bode plot of magnitude and phase response for 1-stage, 2-stage, and 3-stage RC low-pass filters. The study includes theoretical derivations, mathematical modeling, and experimental validation through oscilloscope measurements.

The Bode plot provides insight into the frequency response characteristics of filters, showcasing the attenuation and phase shift as a function of input frequency. This analysis is crucial for designing effective signal conditioning circuits in electronic applications.

The effects of cascading multiple RC stages on frequency response are explored. Practical implementation details, including breadboard setup, expected readings, and component tolerances, are thoroughly discussed. The study aims to bridge theoretical concepts with real-world circuit behavior by comparing calculated and observed responses, emphasizing the importance of low-pass filtering in signal processing applications.

# Contents

<b>Abstract</b>	<b>1</b>
<b>1 One-Stage RC Low-Pass Filter Setup</b>	<b>4</b>
1.1 Single-Stage RC Low-Pass Filter Connection . . . . .	4
1.1.1 Circuit Diagram . . . . .	5
1.1.2 Theoretical equations . . . . .	5
1.1.3 Bode Plot . . . . .	7
<b>2 Two-Stage RC Low-Pass Filter Setup</b>	<b>8</b>
2.1 Two-Stage RC Low-Pass Filter Connection . . . . .	8
2.1.1 Circuit Diagram . . . . .	8
2.1.2 Theoretical equations . . . . .	9
2.1.3 Bode Plot . . . . .	10
<b>3 Three-Stage RC Low-Pass Filter Setup</b>	<b>11</b>
3.1 Three-Stage RC Low-Pass Filter Connection . . . . .	11
3.1.1 Circuit Diagram . . . . .	11
3.1.2 Theoretical equations . . . . .	12
3.1.3 Bode Plot . . . . .	13

# List of Figures

1.1	1-Stage RC Low-Pass Filter . . . . .	5
1.2	1 stage bode plot . . . . .	7
2.1	2-Stage RC Low-Pass Filter . . . . .	8
2.2	2 stage bode plot . . . . .	10
3.1	Three-Stage RC Low-Pass Filter Circuit . . . . .	11
3.2	3 stage bode plot . . . . .	13

# Chapter 1

## One-Stage RC Low-Pass Filter Setup

### 1.1 Single-Stage RC Low-Pass Filter Connection

A single-stage RC low-pass filter consists of a resistor and capacitor connected in series, where the output is taken across the capacitor. The circuit is configured as follows:

- Resistor:  $R = 10k\Omega$
- Capacitor:  $C = 0.01\mu F$
- Function generator providing sinusoidal input
- Oscilloscope for measuring voltage response

#### Breadboard Connections

1. Place the resistor and capacitor in series on the breadboard.
2. Connect the input signal to one end of the resistor.
3. Connect the other end of the resistor to one terminal of the capacitor.
4. Connect the remaining terminal of the capacitor to the ground.
5. Attach oscilloscope probes across the capacitor to observe the output.

### 1.1.1 Circuit Diagram

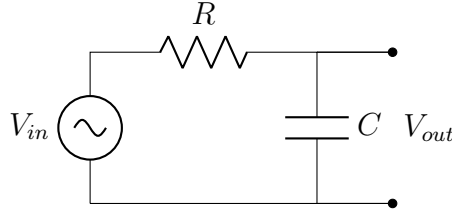


Figure 1.1: 1-Stage RC Low-Pass Filter

### 1.1.2 Theoretical equations

The expected output voltage is given by:

$$H_1(\omega) = \frac{1}{1 + j\omega RC} \quad (1.1)$$

$$|H_1(\omega)| = \frac{1}{\sqrt{1 + (\omega RC)^2}} \quad (1.2)$$

$$\theta_1(\omega) = -\tan^{-1}(\omega RC) \quad (1.3)$$

The magnitude response in decibels (dB) is given by:

$$20 \log_{10} |H(\omega)| \quad (1.4)$$

The phase response in degrees is:

$$\theta(\omega) \times \frac{180}{\pi} \quad (1.5)$$

where  $H(j\omega)$  is the transfer function.

## 1-Stage RC Low-Pass Filter Analysis

$f(\text{Hz})$	$V_{in}(\text{V})$	$V_{out}$ Theoretical(V)	$V_{out}$ Experimental(V)	$\Delta t$
100	2.161	2.157	2.081	$-98.000\mu s$
500	2.161	2.062	1.921	$-94.892\mu s$
1000	2.161	1.830	1.681	$-87.783\mu s$
1590	2.161	1.529	1.441	$-76.068\mu s$
3000	2.161	1.013	1.041	$-55.457\mu s$
5000	2.161	0.655	0.700	$-41.191\mu s$
10000	2.161	0.340	0.384	$-24.488\mu s$

Table 1.1: 1-Stage RC Low-Pass Filter Analysis

- The values of  $\Delta t$  are taken by measuring difference between peaks.
- The signs of  $\Delta t$  were placed according to the theory for correct phase plot.

### 1.1.3 Bode Plot

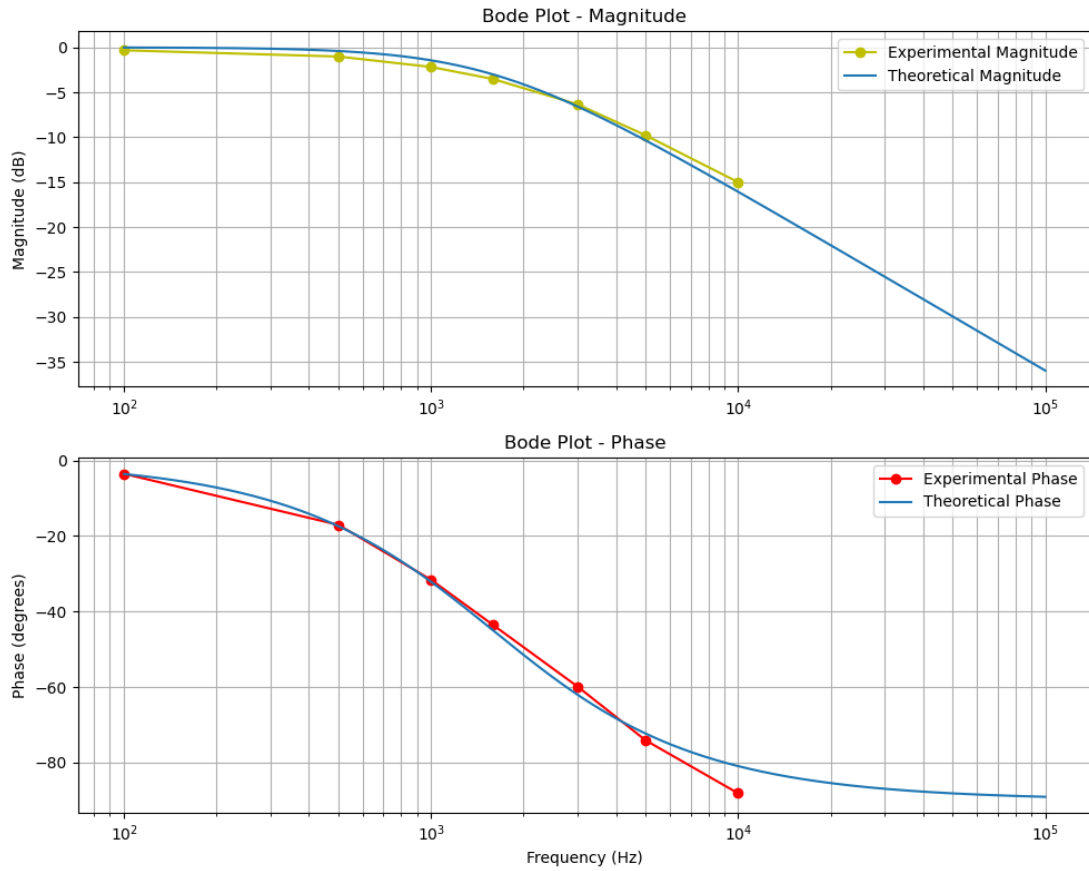
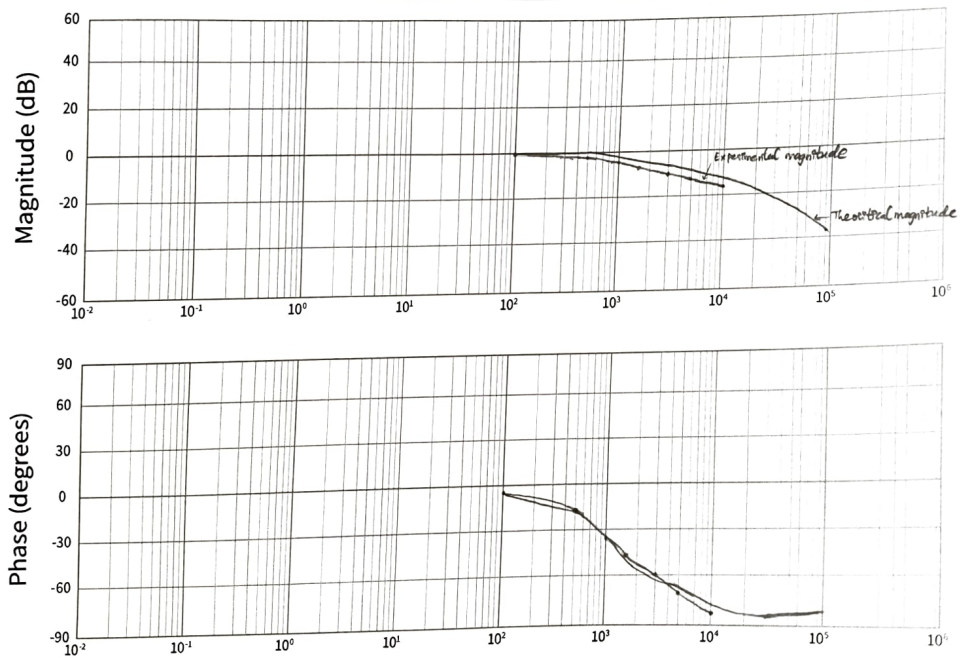


Figure 1.2: 1 stage bode plot

At low frequencies, the output approximates the input signal. As frequency increases, the magnitude decreases at a rate of  $-20$  dB/decade beyond the cutoff frequency  $f_c = \frac{1}{2\pi RC}$ .





## Chapter 2

# Two-Stage RC Low-Pass Filter Setup

### 2.1 Two-Stage RC Low-Pass Filter Connection

When two RC stages are cascaded, the attenuation increases, resulting in sharper roll-off characteristics. The addition of another RC network significantly enhances the filtering effect. Make circuit connection as shown

#### 2.1.1 Circuit Diagram

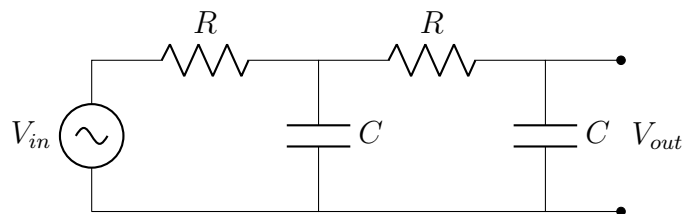


Figure 2.1: 2-Stage RC Low-Pass Filter

### 2.1.2 Theoretical equations

The expected output voltage is given by:

$$H_2(\omega) = \frac{1}{1 + (j\omega RC)^2 + 3j\omega RC} \quad (2.1)$$

$$|H_2(\omega)| = \frac{1}{\sqrt{(1 - (\omega RC)^2)^2 + (3\omega RC)^2}} \quad (2.2)$$

$$\theta_2(\omega) = -\tan^{-1} \left( \frac{3\omega RC}{1 - (\omega RC)^2} \right) \quad (2.3)$$

The magnitude response in decibels (dB) is given by:

$$20 \log_{10} |H(\omega)| \quad (2.4)$$

The phase response in degrees is:

$$\theta(\omega) \times \frac{180}{\pi} \quad (2.5)$$

where  $H(j\omega)$  is the transfer function.

## 2-Stage RC Low-Pass Filter Analysis

$f(\text{Hz})$	$V_{in}(\text{V})$	$V_{out}$ Theoretical(V)	$V_{out}$ Experimental(V)	$\Delta t$
100	2.161	2.132	2.052	-303.240 $\mu s$
500	2.161	1.657	1.498	-262.410 $\mu s$
1000	2.161	1.092	1.041	-203.920 $\mu s$
1590	2.161	0.721	0.687	-162.170 $\mu s$
3000	2.161	0.348	0.362	62.952 $\mu s$
5000	2.161	0.167	0.184	26.612 $\mu s$
10000	2.161	0.050	0.071	7.894 $\mu s$

Table 2.1: 2-Stage RC Low-Pass Filter Analysis

- The values of  $\Delta t$  are taken by measuring difference between peaks.
- The signs of  $\Delta t$  were placed according to the theory for correct phase plot.

### 2.1.3 Bode Plot

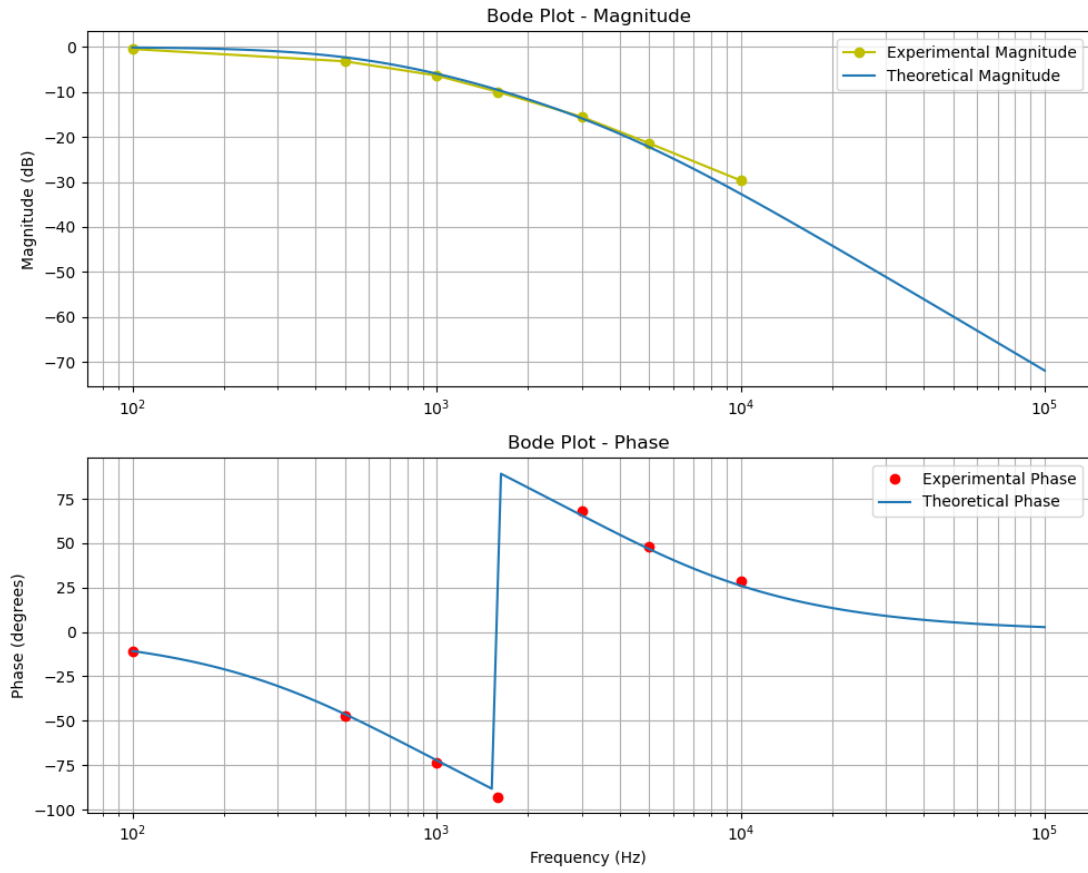
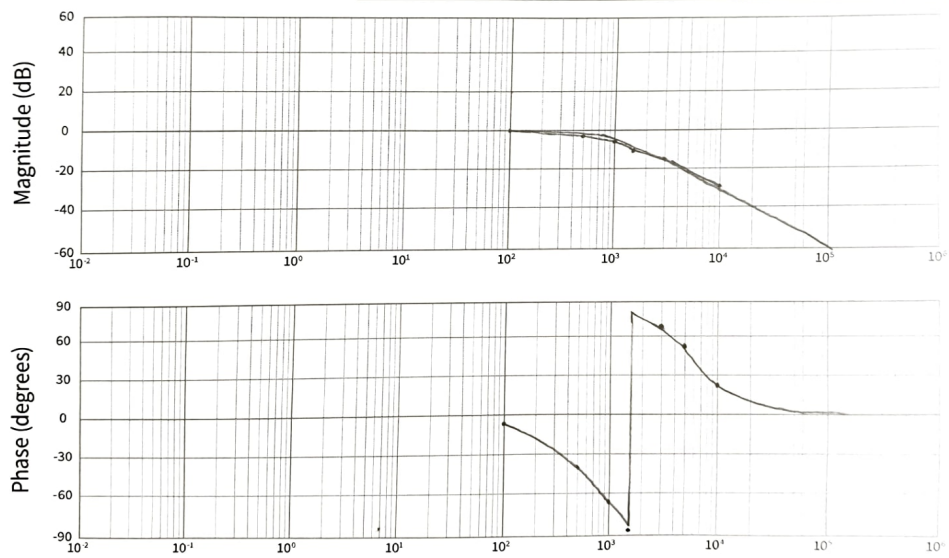


Figure 2.2: 2 stage bode plot

At low frequencies, the output approximates the input signal. As frequency increases, the magnitude decreases at a rate of  $-40$  dB/decade beyond the cutoff frequency  $f_c = \frac{1}{2\pi RC}$



# Chapter 3

## Three-Stage RC Low-Pass Filter Setup

### 3.1 Three-Stage RC Low-Pass Filter Connection

A three-stage RC low-pass filter provides even sharper roll-off characteristics, achieving  $-60$  dB/decade attenuation. This makes it highly effective for applications requiring significant noise suppression. Set up the connections as shown

#### 3.1.1 Circuit Diagram

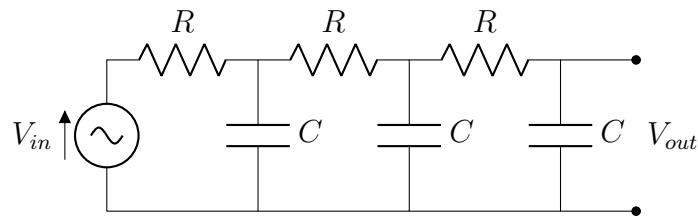


Figure 3.1: Three-Stage RC Low-Pass Filter Circuit

### 3.1.2 Theoretical equations

The expected output voltage is given by:

$$H_3(\omega) = \frac{1}{1 + 6j\omega RC + 5(j\omega RC)^2 + (j\omega RC)^3} \quad (3.1)$$

$$|H_3(\omega)| = \frac{1}{\sqrt{(1 - 5(\omega RC)^2)^2 + (6\omega RC + (\omega RC)^3)^2}} \quad (3.2)$$

$$\theta_3(\omega) = -\tan^{-1} \left( \frac{6\omega RC + (\omega RC)^3}{1 - 5(\omega RC)^2} \right) \quad (3.3)$$

The magnitude response in decibels (dB) is given by:

$$20 \log_{10} |H(\omega)| \quad (3.4)$$

The phase response in degrees is:

$$\theta(\omega) \times \frac{180}{\pi} \quad (3.5)$$

where  $H(j\omega)$  is the transfer function.

## 3-Stage RC Low-Pass Filter Analysis

$f(\text{Hz})$	$V_{in}(\text{V})$	$V_{out}$ Theoretical(V)	$V_{out}$ Experimental(V)	$\Delta t$
100	2.161	2.058	1.982	-595.621 $\mu s$
500	2.161	1.124	1.041	-426.354 $\mu s$
1000	2.161	0.591	0.601	215.716 $\mu s$
1590	2.161	0.338	0.312	108.669 $\mu s$
3000	2.161	0.124	0.139	45.076 $\mu s$
5000	2.161	0.043	0.056	26.123 $\mu s$
10000	2.161	0.008	0.015	16.787 $\mu s$

Table 3.1: 3-Stage RC Low-Pass Filter Analysis

- The values of  $\Delta t$  are taken by measuring difference between peaks.
- The signs of  $\Delta t$  were placed according to the theory for correct phase plot.

### 3.1.3 Bode Plot

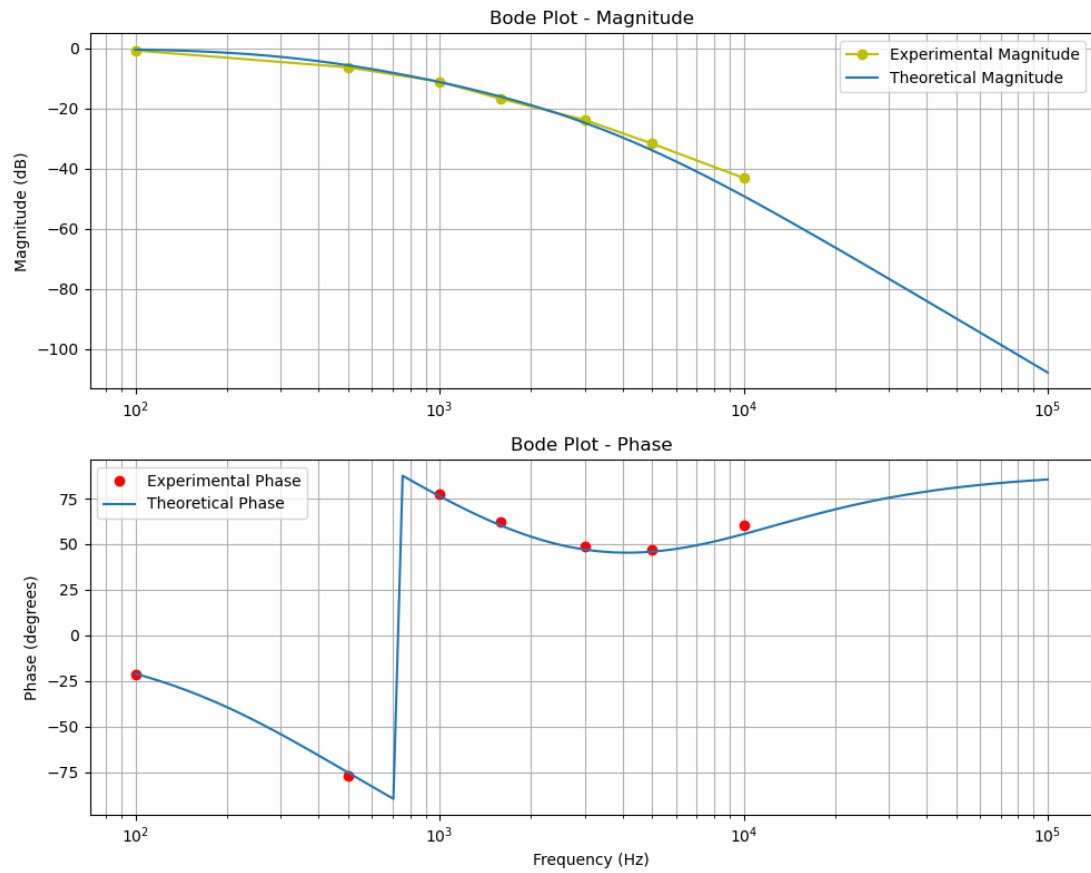


Figure 3.2: 3 stage bode plot



