EE LAB REPORT-3

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CONTENTS

A. Aim

This experiment focuses on obtaining Bode plots (magnitude and phase response) for 1-stage, 2-stage, and 3-stage RC low-pass filters using an oscilloscope and function generator. RC low-pass filters attenuate high-frequency signals while allowing low-frequency signals to pass, with their cutoff frequency determined by the resistor (R) and capacitor (C) values.

B. Appratus used

- Cathode Ray Oscilloscope (CRO).
- Breadboard.
- Function Generator
- BNC Cables.
- Connecting wires.
- Capacitor($100\mu F$)
- Resistor($2K\Omega$)

In our experiment, the value of RC is **0.2 sec**

C. Theory

Transfer function

1) The transfer function of a circuit is the ratio of the output signal (voltage or current) to the input signal (voltage or current) in the frequency domain (s-domain). It describes how the circuit responds to different frequencies.

$$H(s) = \frac{V_{out}}{V_{in}} \text{ or } \frac{I_{out}}{I_{in}} \text{ (where s = j}\omega\text{)} \tag{1}$$

2) From H(s) we can calculate gain(in dB) defined as

$$\text{Gain} = 20log_{10}(H(s))$$

3) From the transfer function, we can also calculate the phase difference which is given by

$$\text{phase}(\omega) = \text{arg}(H(s)) \tag{2}$$

4) The transfer function helps determine the frequency response of a circuit, showing how the circuit amplifies or attenuates different frequencies. This is particularly useful in filters (e.g., low-pass, high-pass, band-pass).

Bode plots

1) A Bode plot is a graphical representation of a system's frequency response. It consists of two separate plots:
   - Magnitude plot (Gain vs log(Frequency))
   - Phase plot (phase vs log(Frequency))

   Magnitude plot
   - X-axis : Logarithmic scale of frequency.
   - Y-axis : 20$\log_{10}$(H(s)) (Magnitude in dB)

   Phase plot
   - X-axis : Logarithmic scale of frequency.
   - Y-axis : $\angle H(jw)$

D. Procedure/Experiment

1) Connect the resistors and capacitors in each stage (Stage-1, Stage-2, Stage-3) such that the output of one RC network feeds into the input of the next, maintaining a cascaded configuration for cumulative frequency response analysis
2) Use a function generator to apply a sine wave of amplitude 5 input across the RC circuit
3) Use the oscilloscope to display both the input and output waveforms
   - Connect Channel 1 across the capacitor to observe the output.
   - Connect Channel 2 to the input (sine wave).
4) To calculate the voltage across the capacitor follow these steps
   a) By using the cursors measure the voltage across the capacitor and label it as V_{out}
   b) Plot the Bode magnitude response by measuring 20$\log \frac{V_{out}}{V_{in}}$ (in dB) for each stage (Stage-1, Stage-2, Stage-3) across a logarithmic frequency scale to analyze the gain roll-off of the RC circuit.
5) To calculate the phase difference, follow these steps
   a) **Calculate Δ X(horizontal shift)**
      - Display both the V_{out} and V_{in} wave forms on the oscilloscope
      - Align there Zero-crossing points horizontally
      - Use the oscilloscope's cursor tool to measure the horizontal distance (Δx) between the corresponding zero crossings V_{in} and V_{out} (rising/falling edge to rising/falling edge)

      Now, the phase difference is given by θ = $(\frac{\Delta X}{T})360°$. It gives θ in degrees

I. STAGE -1

The circuit will be as following

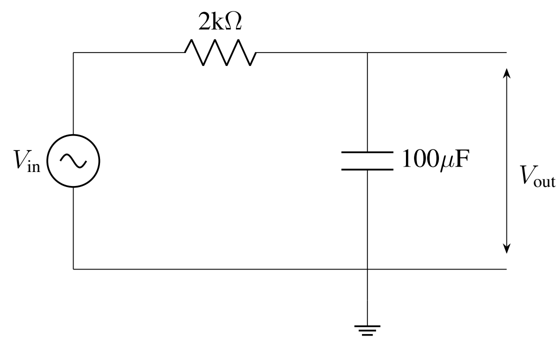


Fig. 1: Circuit Diagram

Calculating transfer function

$$
\begin{aligned}
\frac{V_{out}}{V_{in}} &= \frac{\text{Voltage across capacitor}}{V_{in}} \\
&= \frac{\text{Reactance of capacitor}}{\text{impedance}} \\
&= \frac{\frac{1}{sC}}{\frac{1}{sC} + R} \\
H(s) &= \frac{1}{1 + sRC} \\
H(j\omega) &= \frac{1}{1 + j\omega RC} \\
\text{Gain} &= 20log_{10}|H(j\omega)| \\
&= 20log_{10}\left(\frac{1}{\sqrt{1 + (\omega RC)^2}}\right) \\
&= 20log_{10}\left(\frac{1}{\sqrt{1 + (4 \times 10^{-2})(\omega)^2}}\right) \\
\text{Phase} &= \text{arg}(H(s)) \\
&= -\tan^{-1}(\omega RC)
\end{aligned}
$$

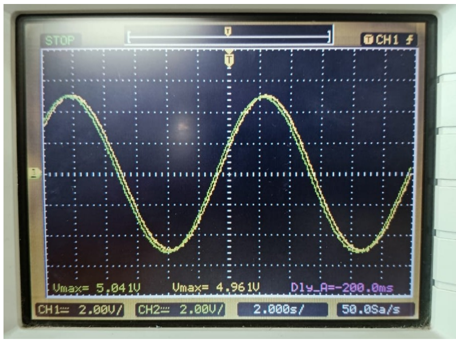
1) If we cascade N identical RC filters, the overall transfer function is given by

$$
\begin{aligned}
H_N(s) &= \left(\frac{1}{1+sRC}\right)^N \\
\text{Gain} &= 20 \times log_{10}|H_N(s)| \\
&= 20 \times Nlog_{10}\left(\frac{1}{\sqrt{1+(\omega RC)^2}}\right) \\
&= -10 \times Nlog(1+(\omega RC)^2) \\
\text{Phase} &= -N\tan^{-1}\omega RC
\end{aligned}
$$

If the phase crosses -180 we will add +360 to phase to make sure that it is in range of 180 to -180

By varying the frequency and calculating the transfer function and phase, we will obtain the below table for stage -1

Here are the figures observed on Oscilloscope for different range of frequencies



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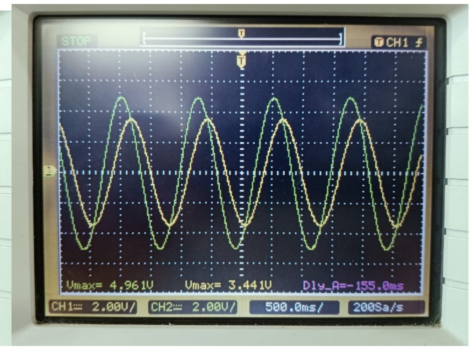

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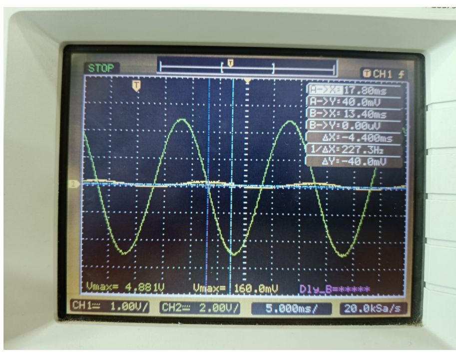

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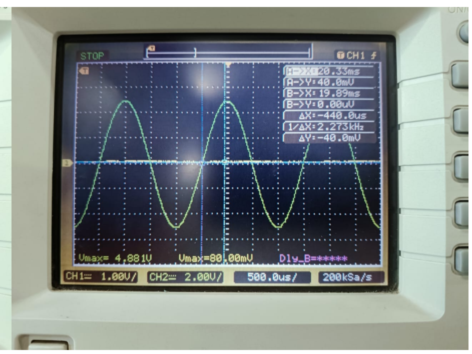


((d)) Caption 4

Fig. 2: Stage-1 figures

By varying the frequency and calculating the transfer function and phase, we obtained the final values from oscilloscope

Frequency	**H(s)**	**Phase**
0.08 Hz	-0.0697	-5.76
0.8 Hz	-3.0033	-44.64
50	-40.0464	-79.2
500 Hz	-60.046	-89.4

These are the bode plots obtained

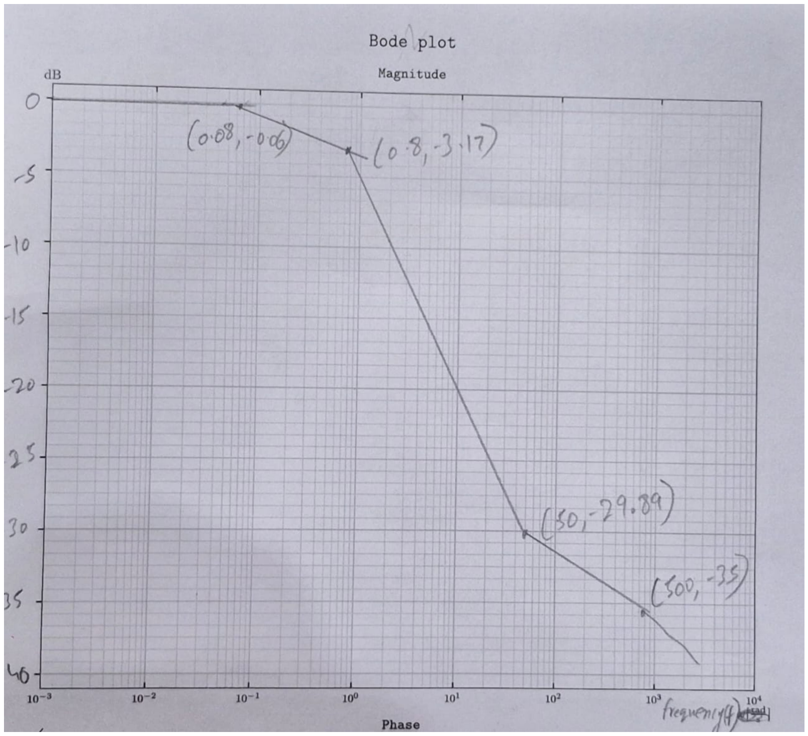


Fig. 3: stage-1 magnitude

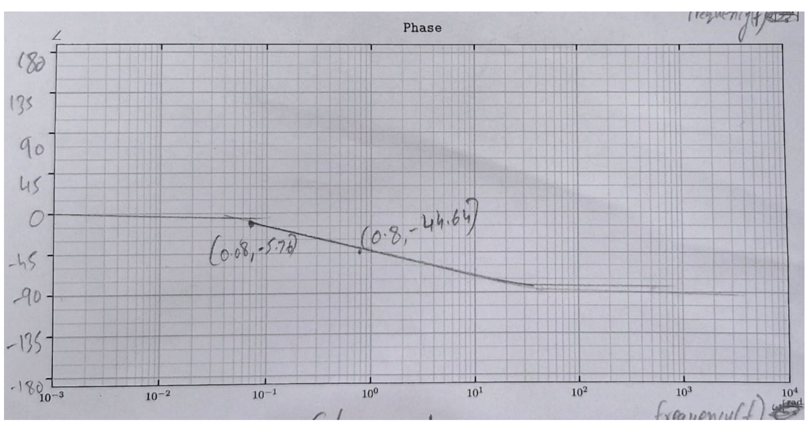


Fig. 4: Stage-1 phase

II. Stage -2

The circuit will be as following

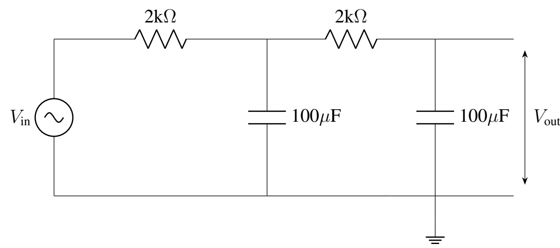


Fig. 5: RC Circuit Diagram

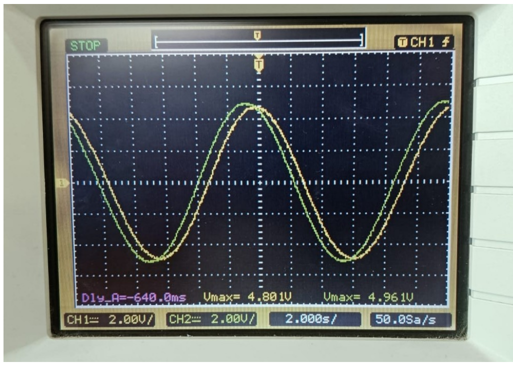
The transfer function for Stage -2 is

$$\begin{aligned} H_2(s) &= \left(\frac{1}{1+sRC}\right)^2 \\ \text{Gain} &= -10 \times 2log(1+(\omega RC)^2) \\ &= -20log(1+(\omega RC)^2) \\ \text{Phase} &= \arg(H(s)) \\ &= -2\tan^{-1}(\omega RC) \end{aligned}$$

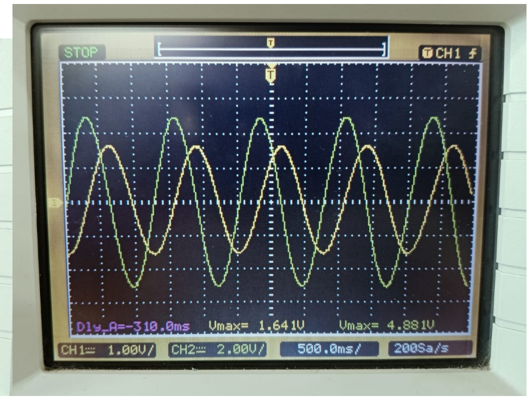
By varying the frequency and calculating the transfer function and phase, we will obtain the below table for stage -2

Frequency	**H(s)**	**Phase**
0.08 Hz	-0.354	-18.43
0.8 Hz	-9.67	-89.28
50	-55.0464	-170.2
500 Hz	-75.046	-179.2

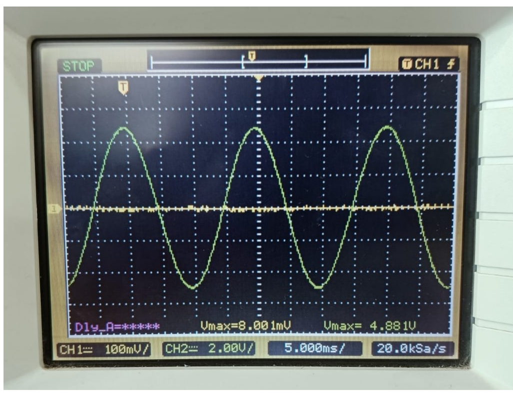
These are the bode plots obtained



((a)) Caption 1



((b)) Caption 2



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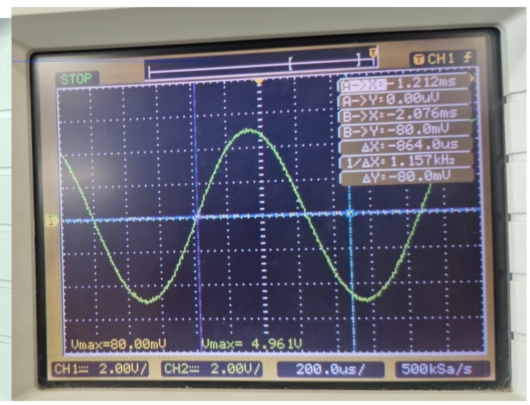
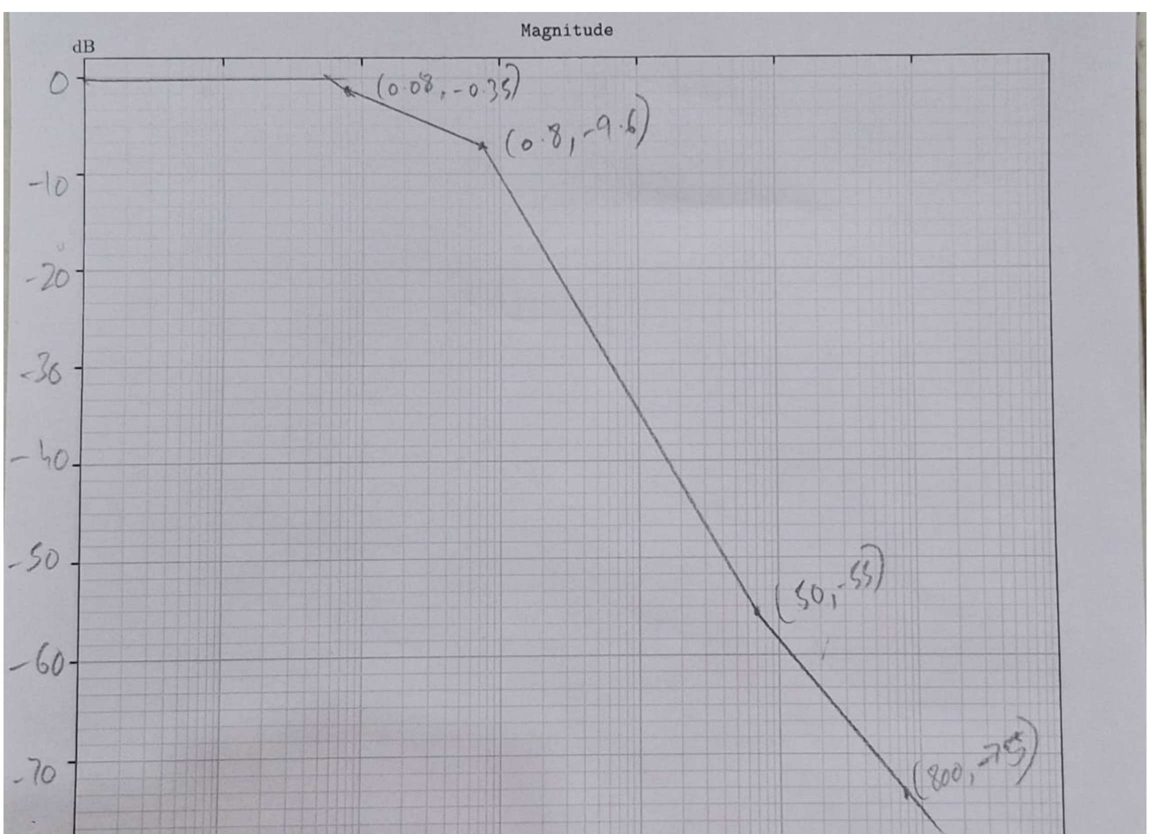


((d)) Caption 4

Fig. 6: Stage-2



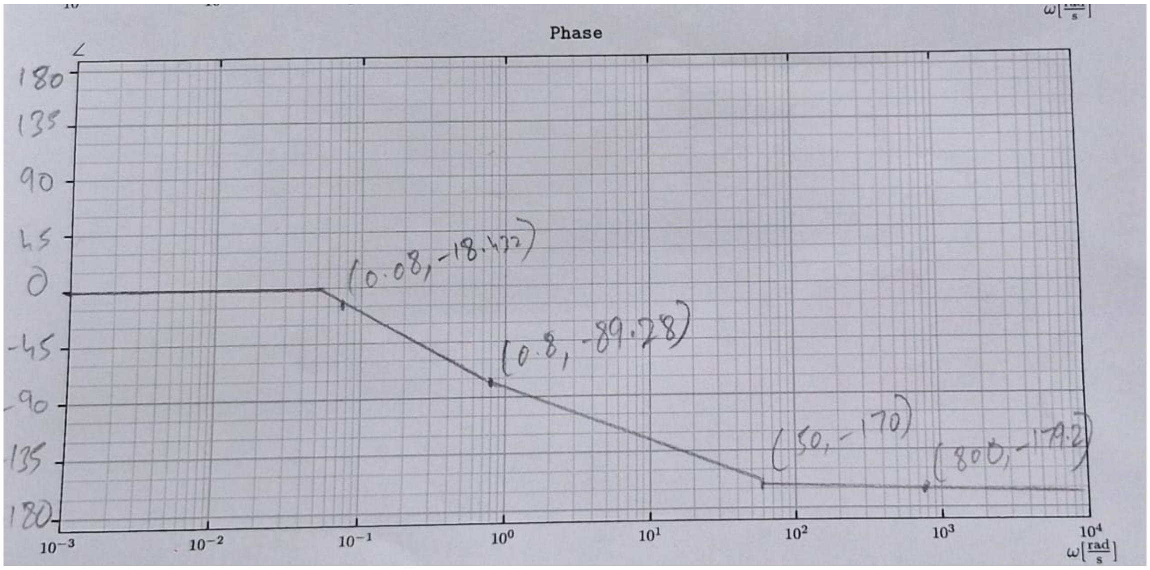


Fig. 8: stage-2 phase

III. STAGE -3

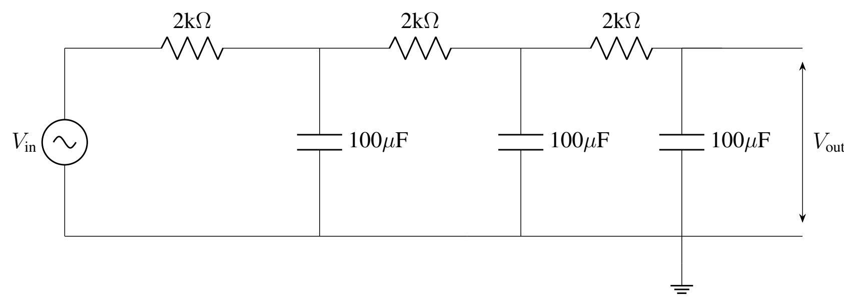


Fig. 9: Three-Stage RC Low-Pass Filter

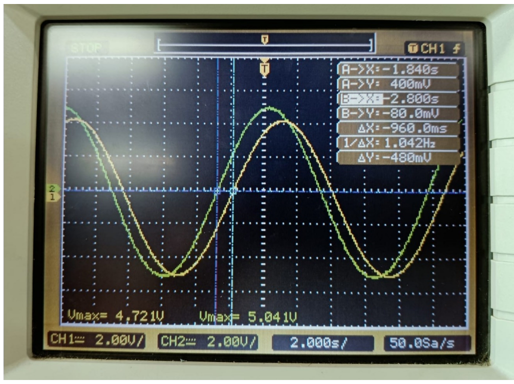
The transfer function for Stage -3 is

$$\begin{aligned} H_3(s) &= \left(\frac{1}{1+sRC}\right)^3 \\ \text{Gain} &= -10 \times 3log(1+(\omega RC)^2) \\ &= -30log(1+(\omega RC)^2) \\ \text{Phase} &= \arg(H(s)) \\ &= -3\tan^{-1}(\omega RC) \end{aligned}$$

By varying the frequency and calculating the transfer function and phase, we will obtain the below table for stage -3

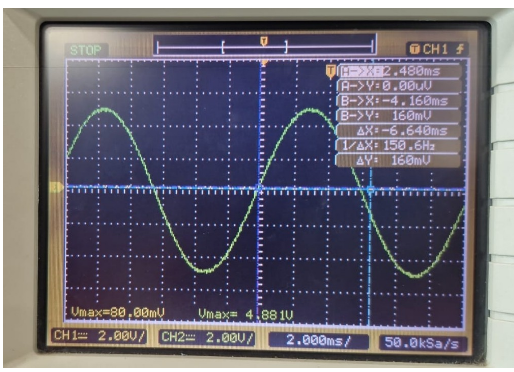
Frequency	**H(s)**	**Phase**
0.08 Hz	-0.554	-27.43
0.8 Hz	-12.38	-132.28
80	-55.0464	168.2
800 Hz	-75.046	111.2

These are the bode plots obtianed



((a)) Caption 1

((b)) Caption 2



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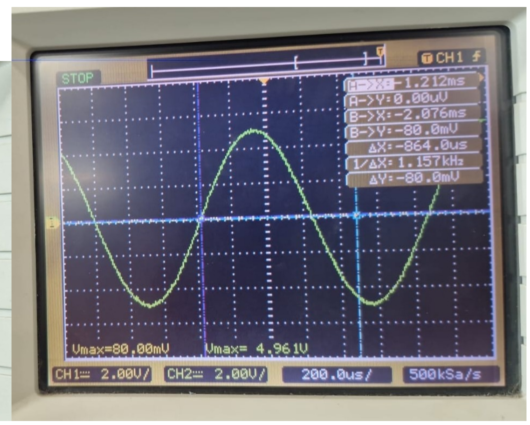
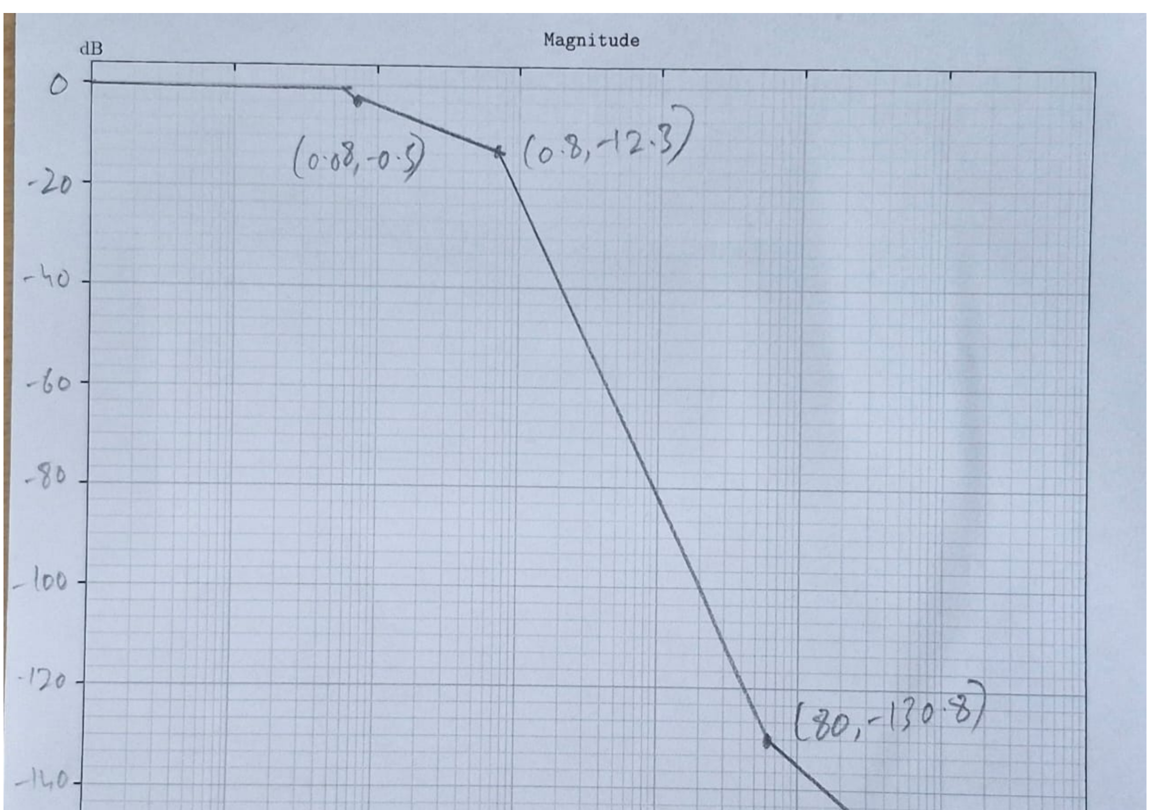


((d)) Caption 4

Fig. 10: Stage-3



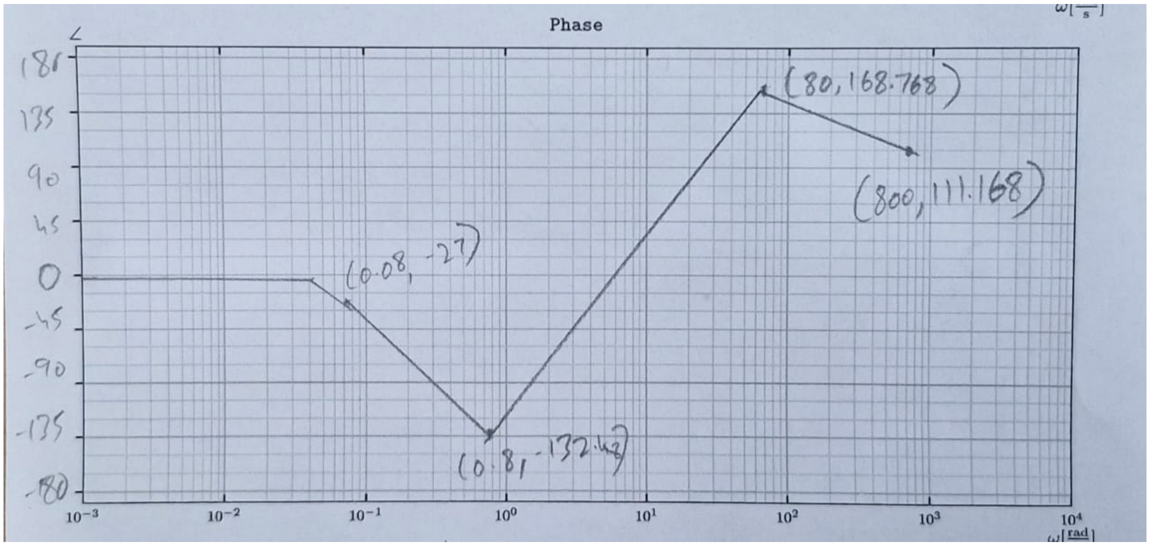


Fig. 12: stage-3 phase