

**CENG4480 Embedded System Development and Applications**  
**The Chinese University of Hong Kong**  
Laboratory 3: Op Active Filters

Student ID:

2018 Fall

## 1 Introduction

This lab session introduces some active filters constructed using op amp. The op amp IC used in this lab is LM324. LM324 contains 4 op amps, we only use one of them.

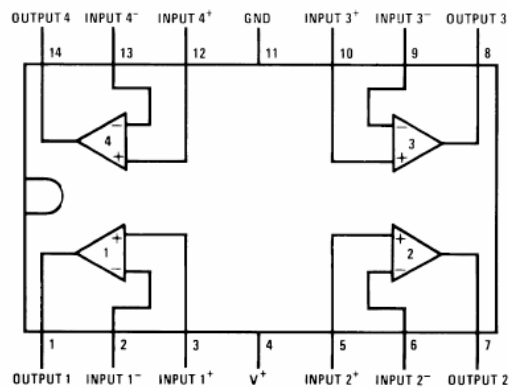


Figure 1: Pinout for the LM324.

### Objectives

By completing this lab session, you should know:

- 1) how to design active filter;
- 2) how to design low pass, high pass, band stop and band pass filter by using op amp.

### Procedures

**Follow the procedures of each experiment. Submit a lab report sheet with your name and student ID to the tutor after the lab. The lab report sheet should have the measurements or plots of your experiments, and answers of the questions asked in this lab manual. You may prepare using a computer document and use a camera to capture the waveforms and insert them in your report.**

## 2 Experiment 1. One-pole low pass filter

In this experiment, you will construct and observe the low pass filter. Measure the input and output waveforms. The following apparatus will be provided:

- 1) a power supply;
- 2) an oscilloscope;
- 3) a breadboard;
- 4) resistors:  $3 \times 1K\Omega$ ;
- 5) capacitor:  $1 \times 0.1\mu F$
- 6) one LM324 IC.

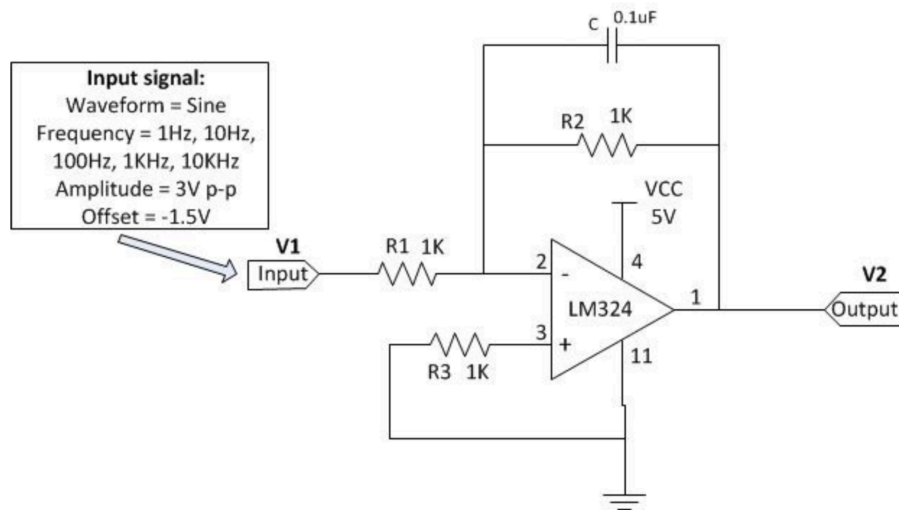


Figure 2: Low pass filter.

### Procedures

- 1) Use pinout diagram for LM324 op amp IC shown in Figure 1 to construct the low pass filter circuit as shown in Figure 2.
- 2) Configure the waveform generator on the oscilloscope with following settings:
  - Waveform=Sine
  - Frequency=1Hz, 10Hz, 100Hz, 1KHz and 10KHz
  - Amplitude=3V p-p
  - Offset=-1.5V
- 3) Connect the waveform generator output to the input of low pass filter;
- 4) Connect channel 1 input (X) of the oscilloscope to the output of low pass filter and connect channel 2 input (Y) of the oscilloscope to the input of low pass filter.

- 5) Measure  $V_1$  and  $V_2$  on the input and output of low pass filter by using the measurement function on the oscilloscope. It is more suitable to use **AC RMS-Cyc** to measure  $V_1$  and  $V_2$ .
- 6) In your lab report,
  - a) Fill the blanks of the table below:  $(G=20 \log_{10} \frac{V_2}{V_1} dB)$
  - b) Plot the Frequency Response curve using semi log graph or use Excel to plot the graph.
  - c) Adjust the frequency of **Wave Gen** on the oscilloscope to find out the **Corner frequency** of the low pass filter. The corner frequency is defined as the frequency at  $V_2/V_1 = 0.707$ .
  - d) Measure the Corner frequency of the low pass filter found by measurement. Does it agree with the theoretical corner frequency  $f_c$  by the formula:  $f_c = \frac{1}{2\pi R_2 C} (Hz)$
  - e) State one of the reasons that causing the difference between Corner frequencies  $f_c$  found by measurement and calculation.

Frequency(Hz)	$V_1$ (Volot)	$V_2$ (Volot)	Gain(dB)
1			
10			
100			
1K			
10K			

### 3 Experiment 2. Two-pole low pass filter

In this experiment, you will construct and observe the two-pole low pass filter. Measure the input and output waveforms. The following apparatus will be provided:

- 1) a power supply;
- 2) an oscilloscope;
- 3) a breadboard;
- 4) resistors:  $4 \times 1K\Omega$ ;
- 5) capacitor:  $2 \times 0.1\mu F$
- 6) one LM324 IC.

#### Procedures

- 1) Use pinout diagram for LM324 op amp IC shown in Figure 1 to construct the two-pole low pass filter circuit as shown in Figure 3.
- 2) Configure the waveform generator on the oscilloscope with following settings:
  - Waveform=Sine

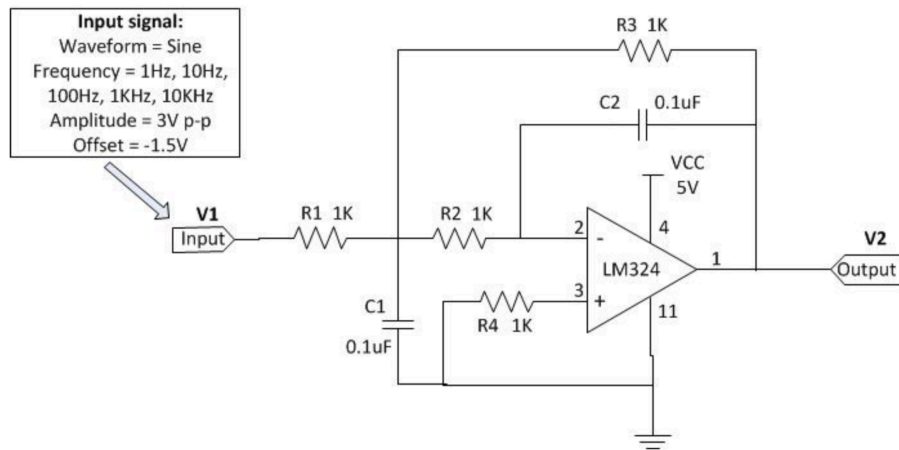


Figure 3: Two-pole Low pass filter.

- Frequency=1Hz, 10Hz, 100Hz, 1KHz and 10KHz
  - Amplitude=3V p-p
  - Offset=-1.5V
- 3) Connect the waveform generator output to the input of two-pole low pass filter;
  - 4) Connect channel 1 input (X) of the oscilloscope to the output of two-pole low pass filter and connect channel 2 input (Y) of the oscilloscope to the input of two-pole low pass filter.
  - 5) Measure  $V_1$  and  $V_2$  on the input and output of low pass filter by using the measurement function on the oscilloscope. It is more suitable to use **AC RMS-Cyc** to measure  $V_1$  and  $V_2$ .
  - 6) In your lab report,
    - a) Fill the blanks of the table below:  $(G=20 \log_{10} \frac{V_2}{V_1} dB)$
    - b) Plot the Frequency Response curve using semi log graph or use Excel to plot the graph. Compare and write down the differences of the frequency responses the one-pole low pass filter (in experiment 1) and the two-pole low pass filter (experiment 2 here).
    - c) Adjust the frequency of **Wave Gen** on the oscilloscope to find out the **Corner frequency** of this low pass filter. The corner frequency is defined as the frequency at  $V_2/V_1(-6dB) = 0.5011$ .
    - d) Measure the Corner frequency of this low pass filter found by measurement. Does it agree with the theoretical corner frequency  $f_c$  by the formula:  $f_c = \frac{1}{2\pi\sqrt{R_2R_3C_1C_2}} = \frac{1}{2\pi R_3C_2} (Hz)$ , (since  $R_2 = R_3, C_1 = C_2$ )

## 4 Experiment 3. High pass filter

In this experiment, you will construct and observe the high pass filter. Measure the input and output waveforms. The following apparatus will be provided:

- 1) a power supply;

Frequency(Hz)	V <sub>1</sub> (Volot)	V <sub>2</sub> (Volot)	Gain(dB)
1			
10			
100			
1K			
10K			

- 2) an oscilloscope;
- 3) a breadboard;
- 4) resistors:  $1 \times 10K\Omega$ ,  $1 \times 8.2K\Omega$ ;
- 5) capacitor:  $1 \times 0.1\mu F$
- 6) one LM324 IC.

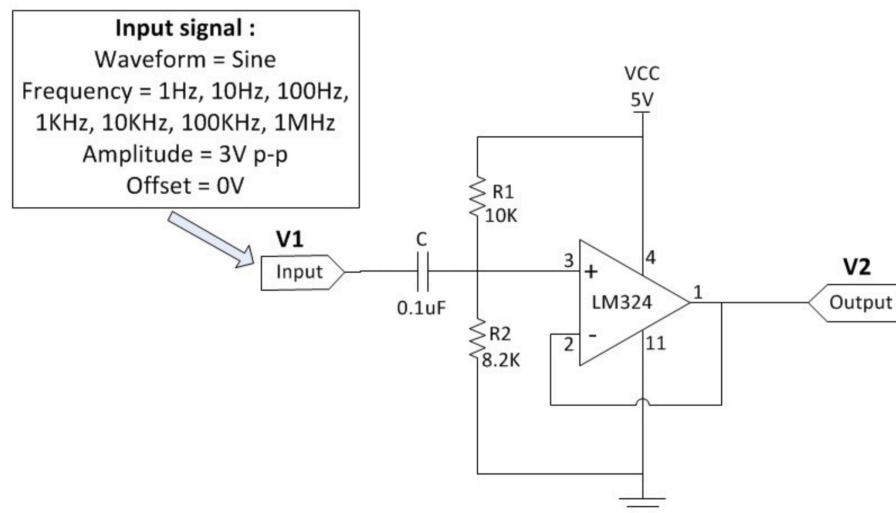


Figure 4: High pass filter.

## Procedures

- 1) Use pinout diagram for LM324 op amp IC shown in Figure 1 to construct the high pass filter circuit as shown in Figure 4.
- 2) Configure the waveform generator on the oscilloscope with following settings:
  - Waveform=Sine
  - Frequency=1Hz, 10Hz, 100Hz, 1KHz , 10KHz, 100KHz and 1MHz
  - Amplitude=3V p-p
  - Offset=0V
- 3) Connect the waveform generator output to the input of high pass filter;

- 4) Connect channel 1 input ( $X$ ) of the oscilloscope to the output of high pass filter and connect channel 2 input ( $Y$ ) of the oscilloscope to the input of high pass filter.
- 5) Measure  $V_1$  and  $V_2$  on the input and output of high pass filter by using the measurement function on the oscilloscope. It is more suitable to use **AC RMS-Cyc** to measure  $V_1$  and  $V_2$ .
- 6) In your lab report,
  - a) Fill the blanks of the table below: ( $G=20 \log_{10} \frac{V_2}{V_1} dB$ )

Frequency(Hz)	$V_1$ (Volot)	$V_2$ (Volot)	Gain(dB)
1			
10			
100			
1K			
10K			
100K			
1M			

- b) Plot the Frequency Response curve using semi log graph or use Excel to plot the graph. Explain why the gain of high pass filter drop significantly at very high frequency.
- c) Adjust the frequency of **Wave Gen** on the oscilloscope to find out the **Corner frequency** of the high pass filter,  $f_{cl}$  and  $f_{ch}$ , where  $f_{cl}$  is the Corner frequency at low frequency range and  $f_{ch}$  is the Corner frequency at higher frequency range. The corner frequency is defined as the frequency at  $V_2/V_1 = 0.707$ .
- d) Measure the Corner frequency of the high pass filter found by measurement. Does it agree with the theoretical corner frequency  $f_{cl}$  by the formula:  $f_{cl} = \frac{1}{2\pi RC}(Hz)$ , where  $R = R_1 || R_2$

## 5 Experiment 4. Band stop (notch) filter

In this experiment, you will construct and observe the band stop filter. Measure the input and output waveforms. The following apparatus will be provided:

- 1) a power supply;
- 2) an oscilloscope;
- 3) a breadboard;
- 4) resistors:  $2 \times 10M\Omega, 1 \times 4.7M\Omega$ ;
- 5) capacitor:  $1 \times 390pF, 2 \times 200pF$
- 6) one LM324 IC.

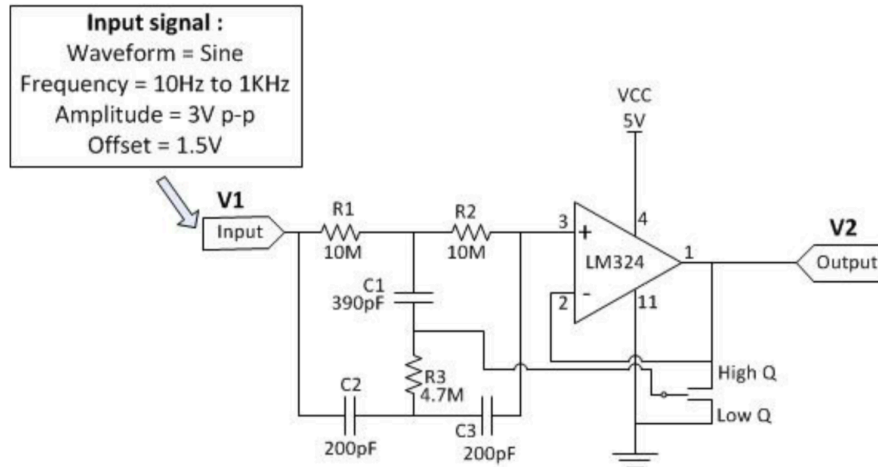


Figure 5: Band stop filter.

## Procedures

- 1) Use pinout diagram for LM324 op amp IC shown in Figure 1 to construct the band stop circuit as shown in Figure 5.
- 2) Configure the waveform generator on the oscilloscope with following settings:
  - Waveform=Sine
  - Frequency=1Hz to 1kHz
  - Amplitude=3V p-p
  - Offset=1.5V
- 3) Connect the waveform generator output to the input of band stop filter;
- 4) Connect channel 1 input (X) of the oscilloscope to the output of band stop filter and connect channel 2 input (Y) of the oscilloscope to the input of band stop filter.
- 5) Connect the band stop filter the Low Q, measure  $V_{1l}$  and  $V_{2l}$  on the input and output of band stop filter by using the measurement function on the oscilloscope. Then connect the band stop filter to High Q, measure  $V_{2h}$ .
- 6) Repeat the step 5 for different frequencies as listed on the table.
- 7) In your lab report,
  - a) Fill the blanks of the table below:  $(G=20 \log_{10} \frac{V_2}{V_1} dB)$
  - b) Plot the both Frequency Response curve of Low Q and High Q band stop filter in the same graph by using semi log graph or using Excel. Compare and comment the Low Q and High Q frequency response curves of band stop filter.

Frequency(Hz)	$V_1$ (Volot)	$V_{2l}$ (Volot)	Low Q Gain(dB)	$V_{2h}$ (Volot)	High Gain(dB)
10					
20					
30					
40					
50					
60					
70					
80					
90					
100					
150					
250					
500					
1K					

## 6 Experiment 5. Non-inverting Schmitt trigger

In this experiment, you will construct and observe the non-inverting filter. Measure the Hysteresis ( $V_{TH} - V_{TL}$ ) with different value of  $R_1$ . The following apparatus will be provided:

- 1) a power supply;
- 2) an oscilloscope;
- 3) a breadboard;
- 4) resistors:  $1 \times 1K\Omega$ ,  $3 \times 10K\Omega$ ,  $1 \times 2K\Omega$ ,  $1 \times 3.9K\Omega$ ,  $1 \times 8.2K\Omega$ ;
- 5) one LM324 IC.

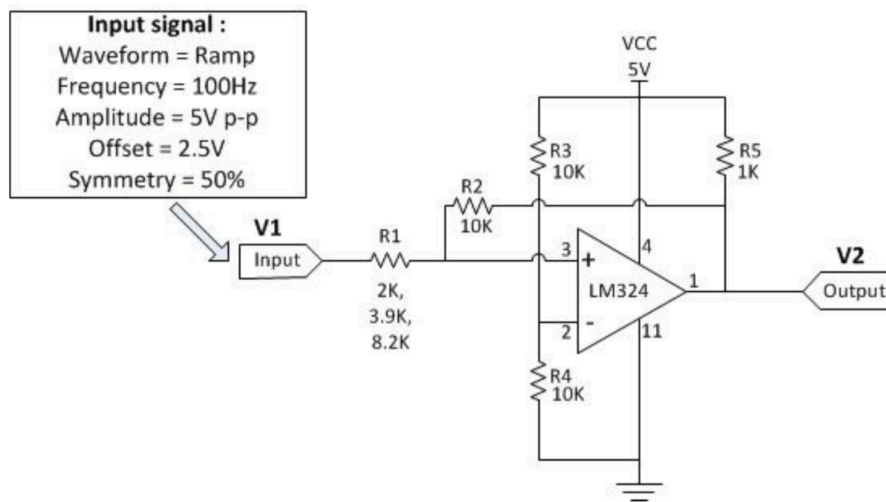


Figure 6: Non-inverting Schmitt trigger.



## Procedures

- 1) Use pinout diagram for LM324 op amp IC shown in Figure 1 to non-inverting Schmitt filter circuit as shown in Figure 6. (Use  $R_1 = 2K\Omega$  at first)
- 2) Configure the waveform generator on the oscilloscope with following settings:
  - Waveform=Ramp
  - Frequency= $100Hz$
  - Amplitude= $5V$  p-p
  - Offset= $2.5V$
  - Symmetry = 50%
- 3) Connect the waveform generator output to the input of low pass filter;
- 4) **Connect channel 1 input (X)** of the oscilloscope to the **output** of non-inverting Schmitt trigger and connect **channel 2 input (Y)** of the oscilloscope to the **output** of non-inverting Schmitt trigger. The waveform displayed on the oscilloscope should be similar to Figure 7.

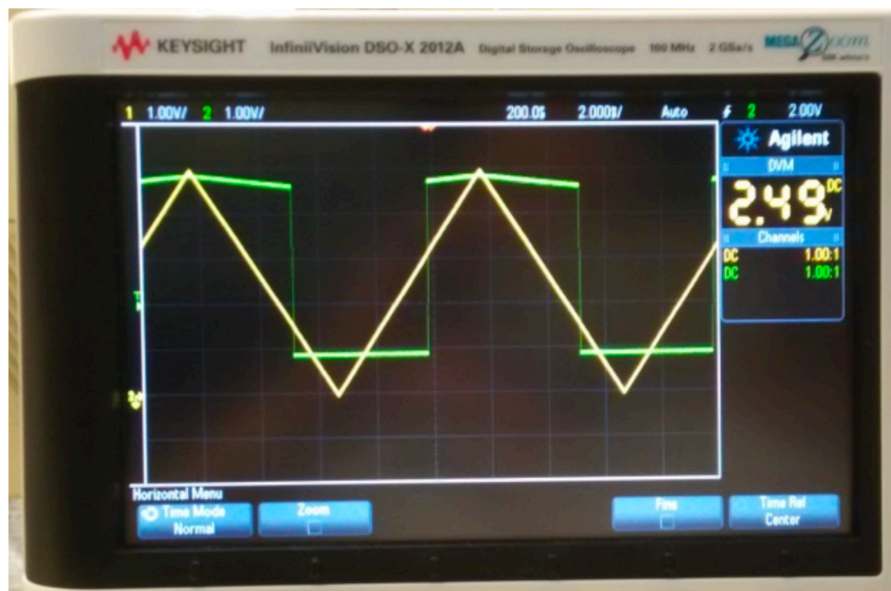


Figure 7: Waveforms of input(X) and input(Y).

- 5) Press the **Horiz** button (on the top of oscilloscope panel near the **Horizontal** knob). Select **XY** Time mode. The waveform displayed on the oscilloscope should be similar to Figure 8.
- 6) Use cursor measurement on the oscilloscope measure the top value of the curve  $V_{ohigh}$ , the bottom value of the curve  $V_{olow}$ , the right value of the curve  $V_{TH}$  and the left value of the curve  $V_{TL}$ .
- 7) Hence measure the Hysteresis of the Schmitt trigger circuit.

$$Hyteresis = V_{TH} - V_{TL} = \Delta X$$

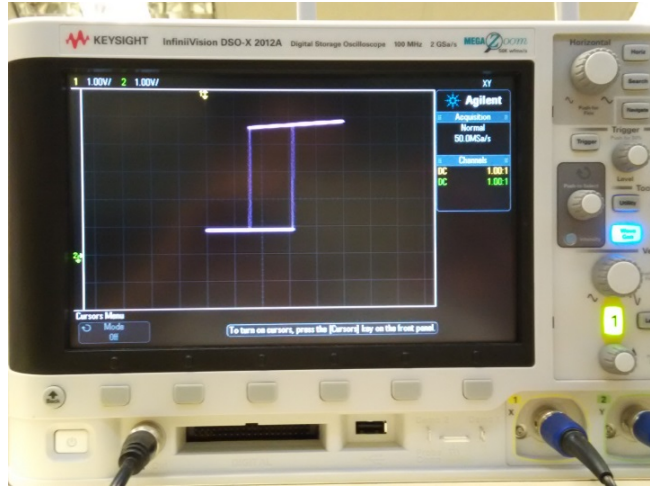


Figure 8: Waveform under XY Time mode.

8) Measure the  $V_{ohigh} - V_{olow}$ ,

$$V_{ohigh} - V_{olow} = \Delta Y(2)$$

hence calculate Hysteresis from

$$\begin{aligned} Hysterisis &= (V_{ohigh} - V_{olow}) \frac{R_1}{R_2} \\ &= \Delta Y(2) \left( \frac{R_1}{R_2} \right) \end{aligned}$$

9) Repeat steps 4 to 6 with  $R_1 = 3.9K\Omega$  and  $R_1 = 8.2K\Omega$

10) In the lab report sheet:

- a) Fill in the table below.
- b) Record and plot the input/output wavaforms displayed on the scope.

$R_1$	$V_{ohigh}$	$V_{olow}$	$V_{TH}$	$V_{TL}$	$Hysterisis = \Delta X$	$Hysterisis = \Delta Y \left( \frac{R_1}{R_2} \right)$
$2K\Omega$						
$3.9K\Omega$						
$8.3K\Omega$						