The Hong Kong University of Science and Technology
Department of Electronic and Computer Engineering

ELEC2400 | **ELECTRONIC CIRCUITS** | FALL 2021-22

LAB 5b – Audio Equalizer

1. Objective

The objectives of this experiment are to design and build a simple analog audio equalizer using operational amplifiers and to provide experience with the applications of operational amplifier.

2. Component and Instrumentation

a. USB Oscilloscope (LOTO Instrument OSC 481S)
b. Digital Multimeter (VC890C)
c. Breadboard
d. LM324 Op Amp ICs

3. Background Information

An audio equalizer is an electronic device to alter the frequency response characteristics of an audio system (e.g. MP3). The equalizer can be implemented in analog domain using passive and active electronic elements or in digital domain with some digital signal processing algorithms. In this experiment, you will design, build and test a simple analog audio equalizer using operational amplifiers.

Peaking equalizer is one of the most popular implementations of audio equalizer. Peaking equalizer can raise or lower the level of a range of frequencies around a central frequency in a bell shape. Some peaking equalizers can control the gain, bandwidth and center frequency. In this experiment, a peaking equalizer will be designed which can adjust the gain (level) of each frequency band. Fig. 1 below shows one implementation of the audio equalizer system with three frequency bands and its frequency characteristic.

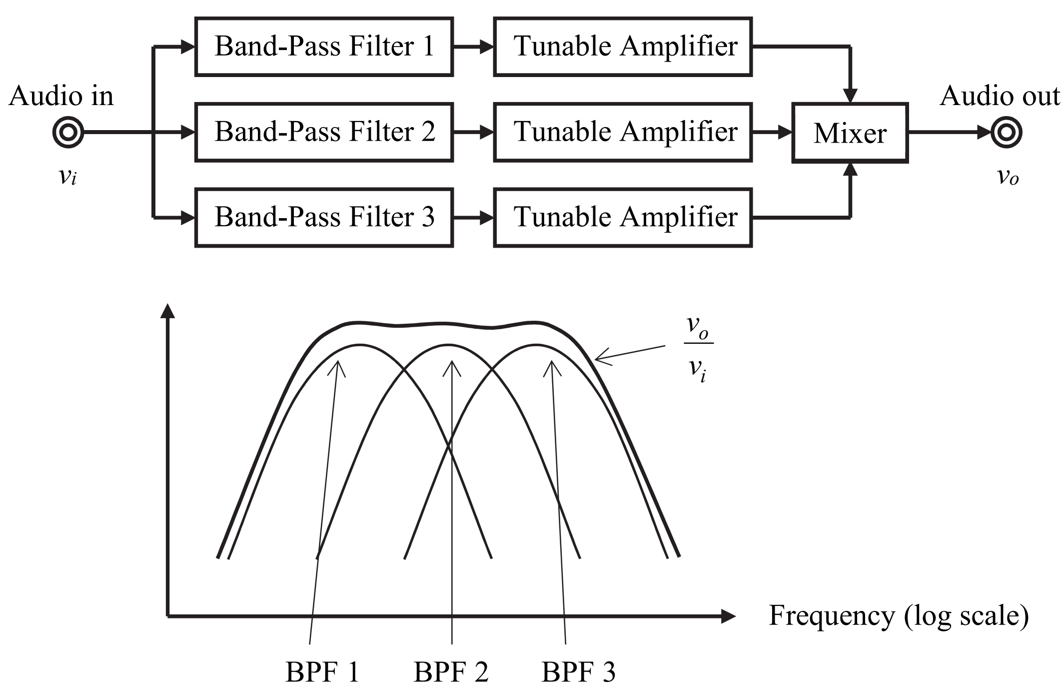


Fig. 1: An audio equalizer system

There are several configurations may be used to realize a band-pass filter. A multiple-feedback band-pass filter is used in this experiment and is shown in Fig. 2 which uses one operational amplifier and five resistors and capacitors.

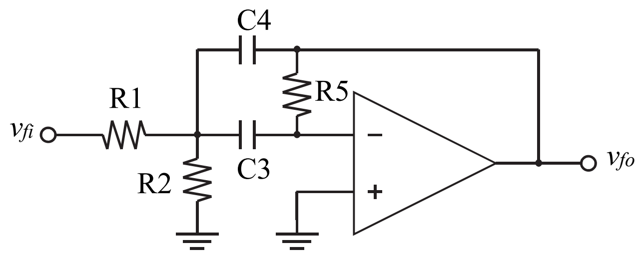


Fig. 2: A band-pass filter

The voltage transfer function is given by

$$\frac{v_{fo}}{v_{fi}} = \frac{-s\left(1/R_1C_4\right)}{s^2 + s\left(1/R_5\right)\left(1/C_3 + 1/C_4\right) + \left(1/R_5C_3C_4\right)\left(1/R_1 + 1/R_2\right)} \tag{1}$$

In terms of the band-pass filter function,

$$H_o = \frac{1}{\left(R_1/R_5\right)\left(1 + C_4/C_3\right)} \tag{2}$$

$$\omega_o = \left[\frac{1}{R_5C_3C_4}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)\right]^{1/2} \tag{3}$$

$$\frac{1}{Q} = \sqrt{\frac{1}{R_5(1/R_1 + 1/R_2)}}\left[\sqrt{\frac{C_3}{C_4}} + \sqrt{\frac{C_4}{C_3}}\right] \tag{4}$$

where H_o is the gain of the pass-band filter at the center frequency ω_o and Q is the Q factor of the band-pass filter. Equations (2) to (5) can be used to design the gain, center frequency and the bandwidth of the band-pass filter. However, the equations are rather complicated and several assumptions can be made to simplify the design. First of all, the gain of the band-pass filter is not very important as the overall gain each frequency band can be adjusted by the tunable amplifier in series with the filter. By setting $C_3 = C_4 = C$ and assuming $R_2 >> R_1$. Equations (3) and (4) can be simplified to

$$\omega_o = \frac{1}{\sqrt{R_5R_1}C} \tag{5}$$

$$\frac{1}{Q} = 2\sqrt{\frac{R_1}{R_5}} \tag{6}$$

Hint: For a 3-band audio equalizer, the Q value of the filter should be smaller than 1.

The complete schematic of the 3-band audio equalizer system is shown in Fig. 3. The tunable amplifiers and the mixer can be realized by an operational amplifier adder together with 3 variable resistors. Rm's are used to set the minimum resistances at the input of the adder and thus limit the maximum gain of the mixer.

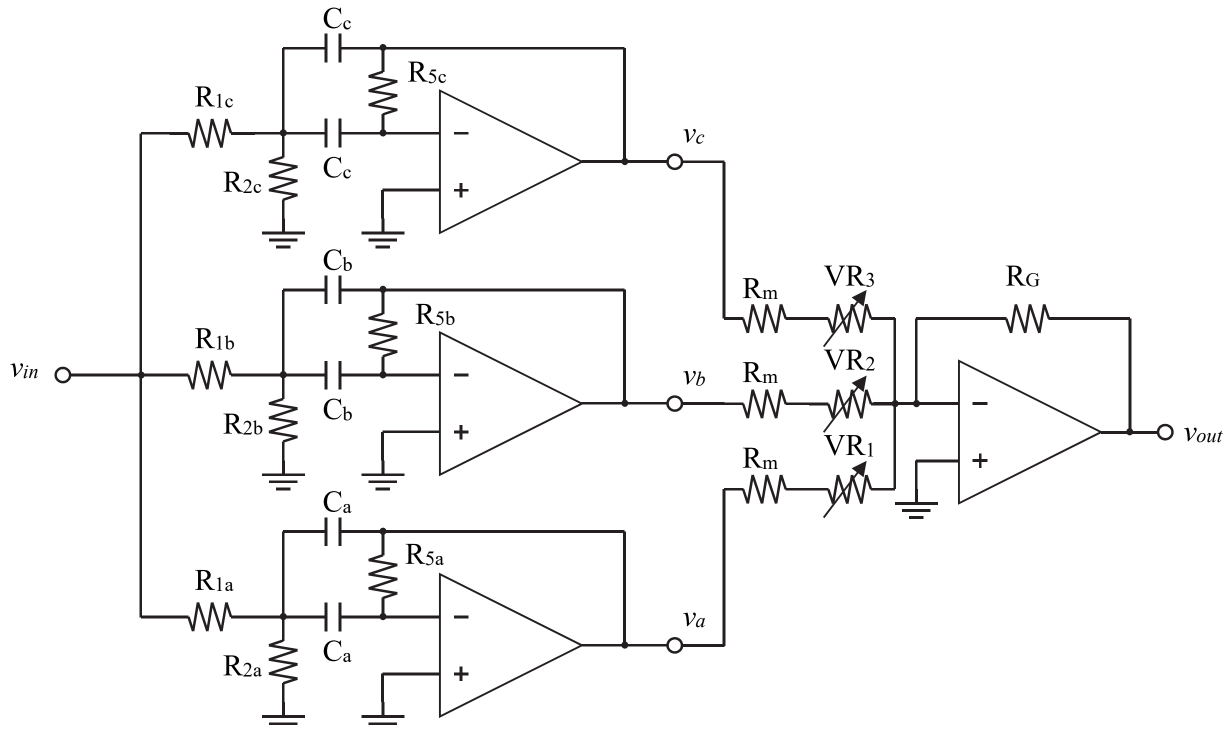


Fig. 3: A 3-band equalizer

4. Prelab

4.1 Obtain all the component values (R_{1a}, R_{2a}, R_{5a}, C_a, R_{1b}, R_{2b}, R_{5b}, C_b, R_{1c}, R_{2c}, R_{5c}, C_c, R_m, VR_1, VR_2, VR_3 and R_G) from lab#5a.

4.2 You have to prepare 6 AA batteries.

5. Procedure

5.1 Important Rules

5.1.1 You would use the 4 AA battery compartment to power up the circuit. In any case, you should not short the VDD and GND.

5.1.2 You should keep one battery off from the battery compartment as shown in Fig. 4, when circuit is not powered up.

5.1.3 Every time you power up the circuit, you should test whether the VDD and GND are shorted or not. If it is not shorted, you can turn it on. If it is shorted, you should not power up and you should check the connection first. You could refer to the video (video1-testing_VDD_and_GND.mp4) for demonstration.

5.1.4 There is a power LED shown in Fig. 14 to indicate the power is ON. Once the board is powered up, you should always check the status of the power LED. It should be ON all the time. If the LED is suddenly OFF after you inserted something or changed wiring, in that case, you have to immediately take off the battery from battery compartment, and you should check your circuit. You could refer to the video (video2-power_LED_suddenly_OFF.mp4)

5.1.5 During the experiment, you try to touch all the components: resistors, and IC, if you could feel that it is hot, please take off battery from battery compartment immediately, and stop the experiment. You consult the TA for advice.

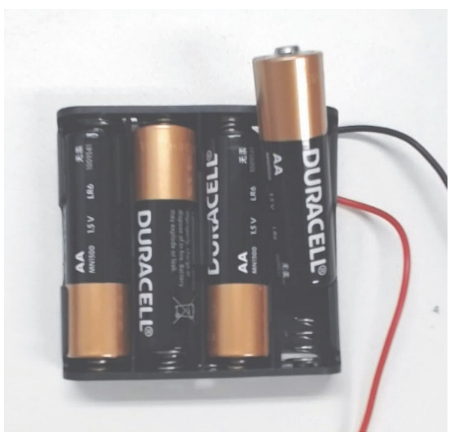
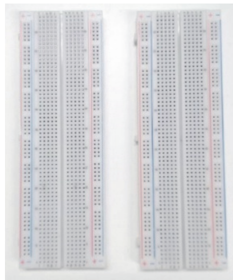


Fig. 4

5.2 Construct the circuit

5.2.1. Combine two breadboards as shown in Fig. 5. You could refer to the video (video3-combine_breadboard.mp4) for demonstration.



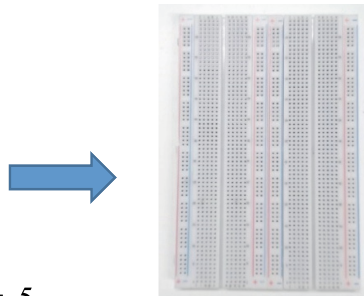


Fig. 5

5.2.2. You would use two 4xAA battery compartment as shown in Fig 6, to provide supply voltage of positive DC 6 Volt (+6V), and supply voltage of negative DC 6 Volt (-6V).

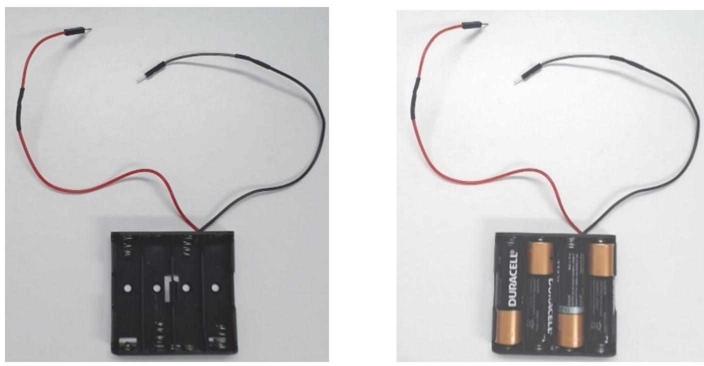


Fig. 6

5.2.3. On the breadboard, connect the columns in a way that two columns for +6V, two columns for -6V, and four columns for GND, as shown in Fig. 7.

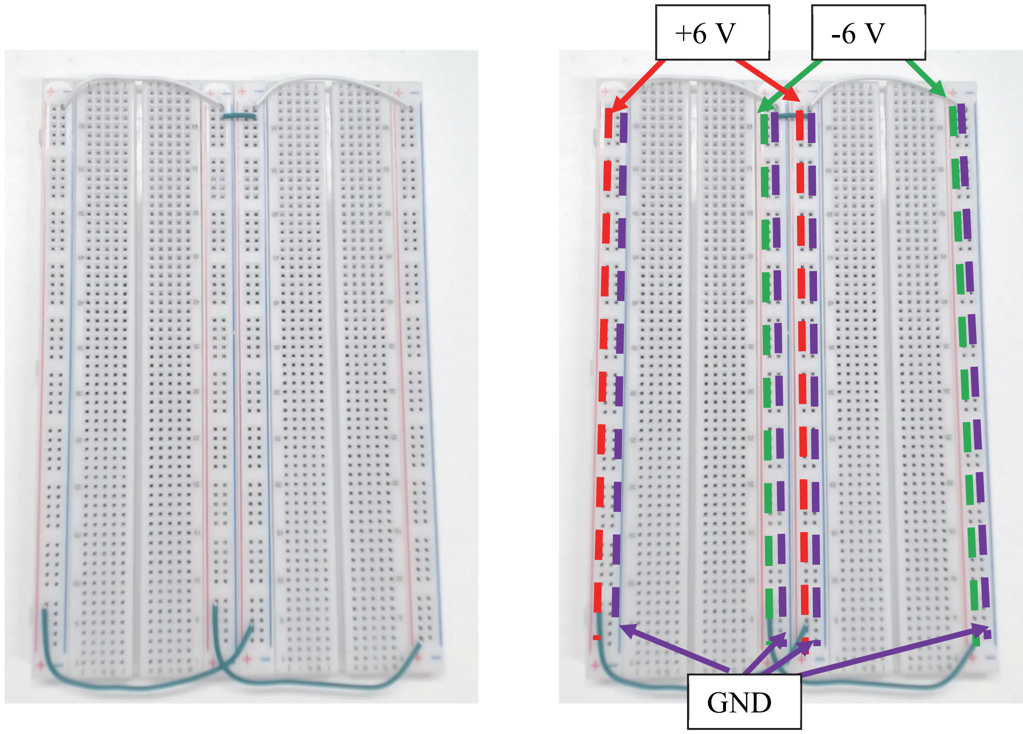


Fig. 7

5.2.4. The power switch, LED, and 330 ohm resistor are shown in Fig. 8. You could cut down the resistor legs if you want, as shown in Fig. 9. Connect two power switches with the LED indication: one for +6V as shown in Fig. 10, and anther one for -6V as shown in Fig. 11. Put all the components on the breadboard as shown in Fig. 12. You could refer to the video (video4-power_switch.mp4) for demonstration.

[Check point 1] Put 4 AA batteries into a 4xAA battery compartment (+6V supply) and put 4 AA batteries into another 4xAA battery compartment (-6V supply). When the power switch-+6V is pressed, the LED_+6V should be ON, and the power switch_-6V is pressed, the LED_-6V should be ON. You could refer to the video (video5-test_power_switch.mp4) for reference.

[WARNING] From now on, if the power switch is pressed, the LED is OFF at any time. You have to immediately switch off the power switch, take off the batteries from the battery compartment, and check the circuit connection. You could also check whether the VDD and GND are shorted by using multimeter.

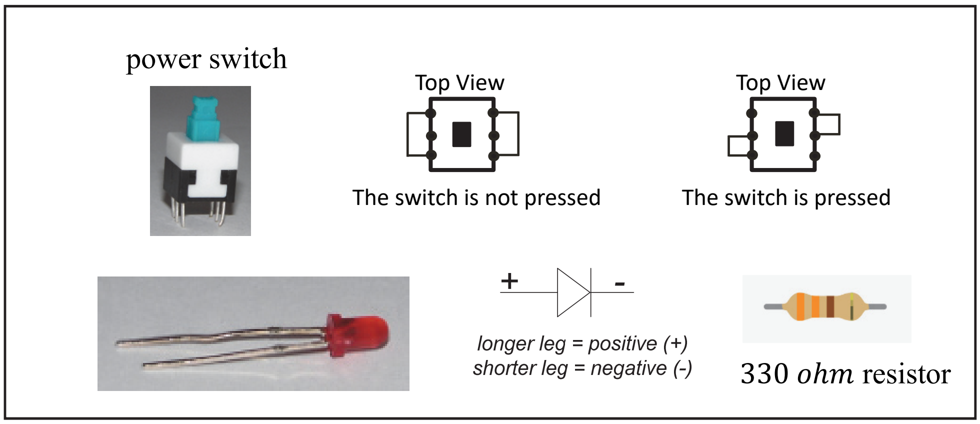
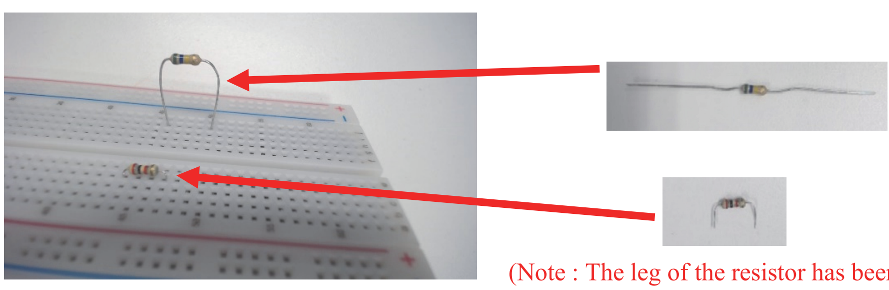


Fig. 8



(Note : The leg of the resistor has been cut down.)

Fig. 9

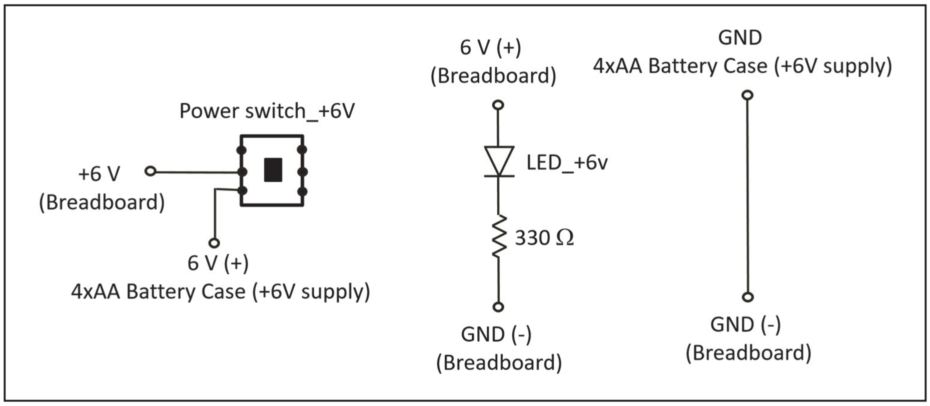


Fig. 10

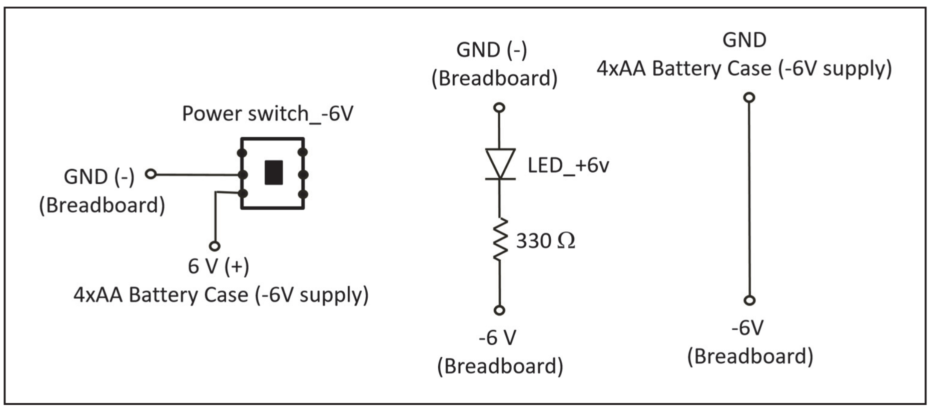
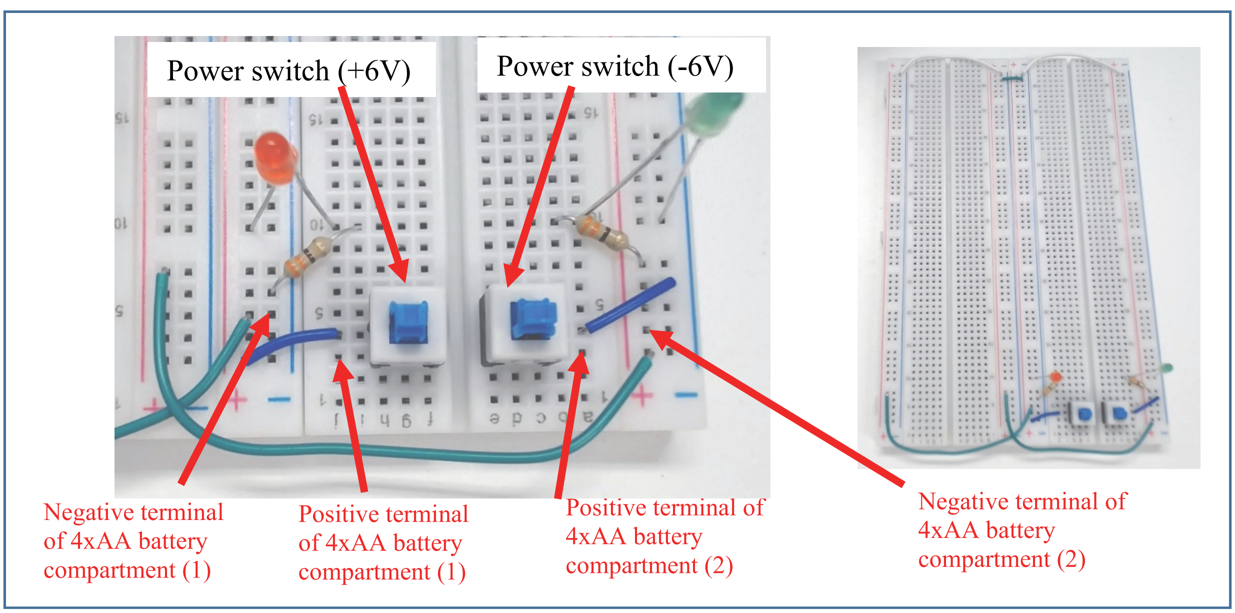


Fig. 11



(Note : The leg of the resistor has been cut down.)

Fig. 12

5.3 Characterize the Band-pass Filter

The LM324 (4 x op amps IC) is shown in Fig. 13. Use the value of the R_{1c}, R_{2c}, R_{5c}, C_c for high frequency band obtained in Lab 5a simulation. Connect the high frequency band-pass filter circuit as shown in Fig. 14, and put all the components on the breadboard as shown in Fig. 15. Don't forget to connect the positive and negative supply. For simplicity, only one opamp is used in each LM324 for each band-pass filer.

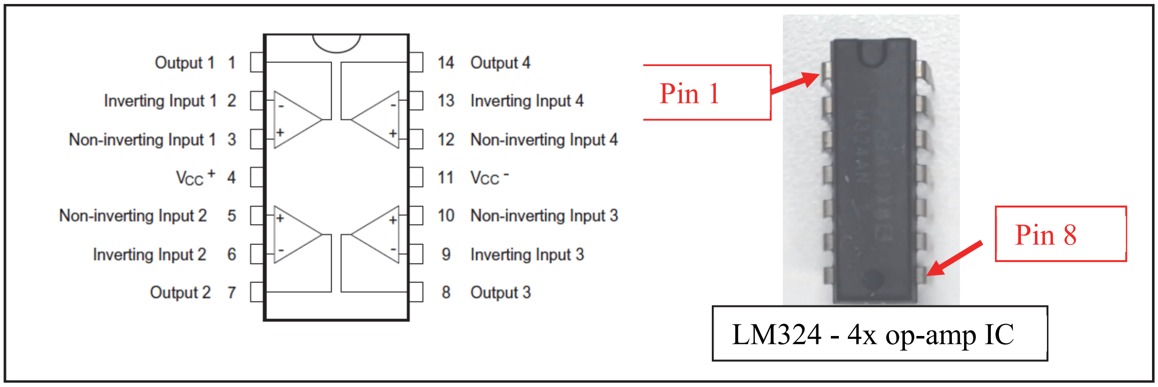


Fig. 13

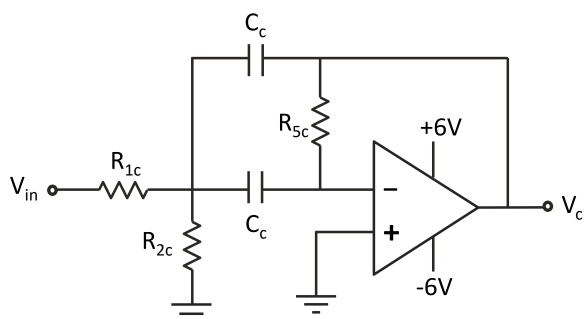


Fig. 14 (high frequency band-pass filter)

WARNING: You should use your simulated result in lab 5a for resistor and capacitor values.

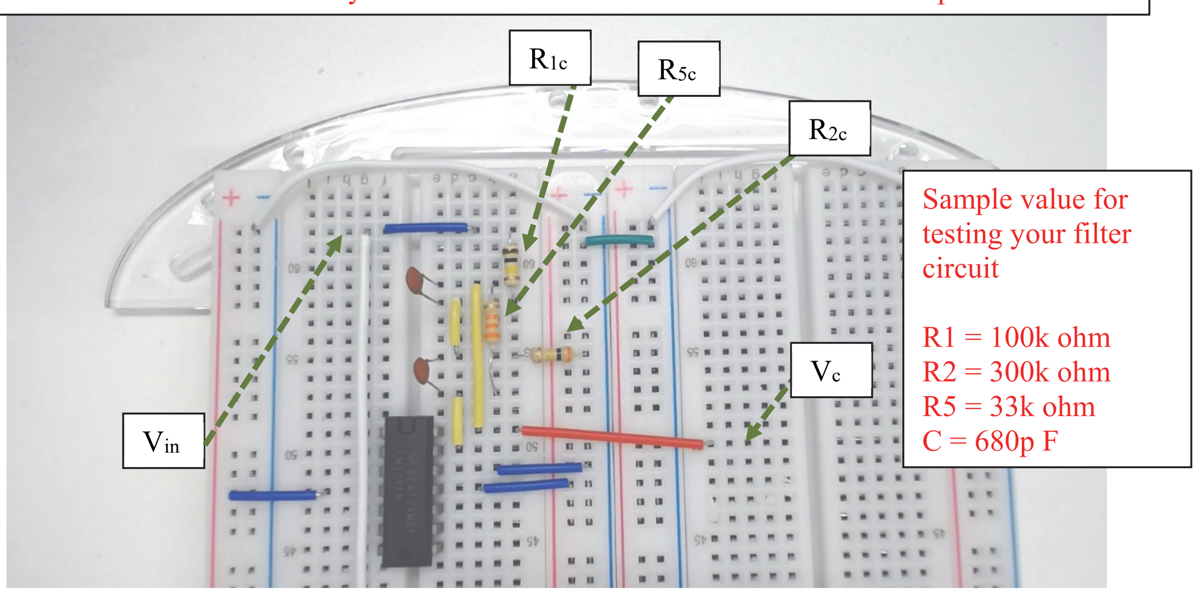


Fig. 15

Connect to the Oscilloscope

5.3.1 You could refer to the video (video6-connect_oscilloscope.mp4) for 5.3.2 – 5.3.5.

5.3.2 Connect the USB oscilloscope to the computer, and start he USB oscilloscope program, as shown in Fig. 16. You should enable “High-Res” for better waveform display.

5.3.3 Connect the function generator output to Vin

5.3.4 Connect Vin to Channel-A

5.3.5 Connect Vc to Channel-B

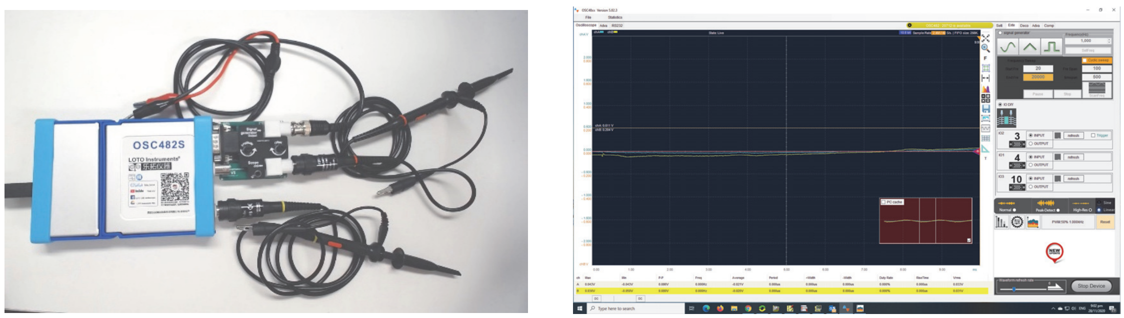


Fig. 16

Setup frequency Sweet

5.3.6 You could refer to the video (video7-set_sweep_frequency.mp4) for 5.3.7 –5.3.13.

5.3.7 Turn on the power switch_+6V and power switch_-6V.

5.3.8 The LED_+6V and LED_-6V should be ON.

5.3.9 Set the x10 on both probes, set x10 for Channel-A and Channel-B on the oscilloscope.

5.3.10 Set 1kHz, 2 Volt peak to peak, 0 Volt offset, SIN wave on function generator.

5.3.11 Adjust the voltage/div scale for Channel-A and for Channel-B, and adjust the sec/div scale for time.

5.3.12 Use frequency sweep function in function generator to change the input signal V_{in}. Set “Start Freq” to 20, “End Freq” to 20000, “Fre span” to 100, and “time span” to 500. (If you want to get more details, you could reduce “Fre span” to 20.)

5.3.13 select “ScanFreq”, the frequency of the Vin would change from 20 Hz to 20000Hz, with the frequency step of 100Hz for every 500ms. (If you want to look at particular frequency range, e.g. from 20 Hz to 3k Hz)

Different ways to read measuring data

5.3.14 There are three ways to monitor the signal changes during the frequency sweeping. One is to look at the waveform, second way is the look at the information on bottom as shown in Fig. 17.

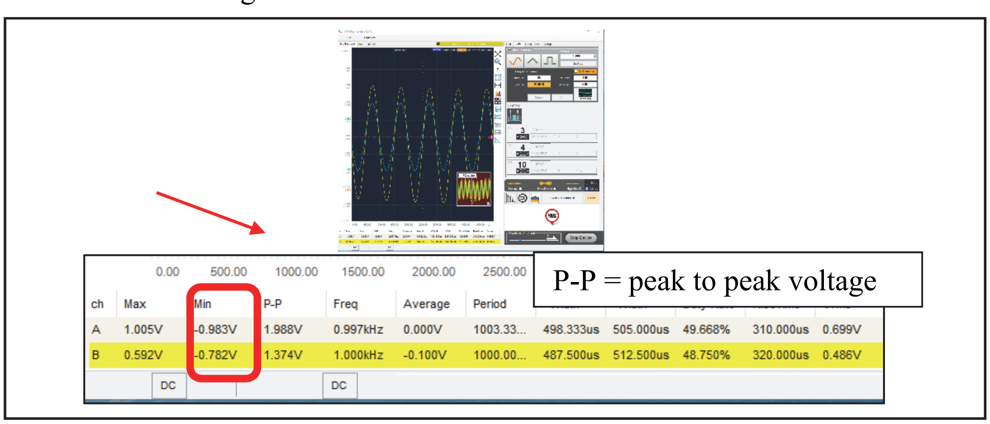
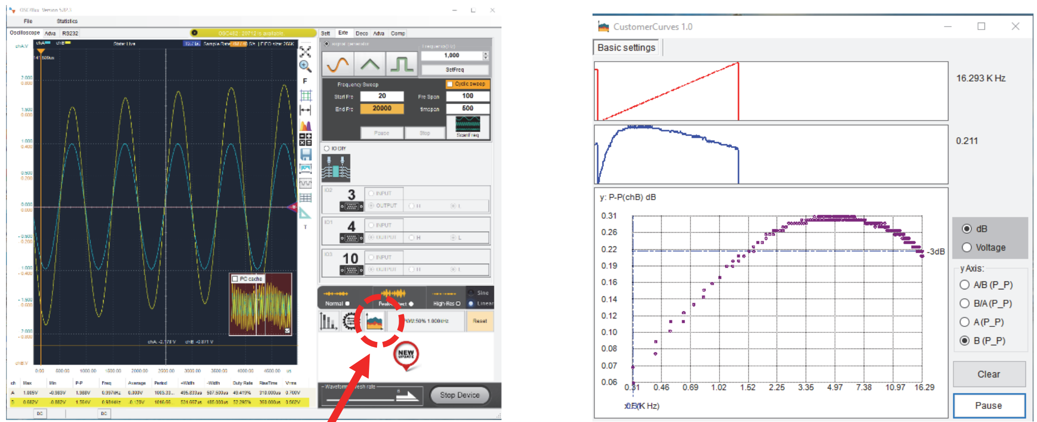


Fig. 17

Use Customer Curves to read frequency spectrum

5.3.15 The third way is to use the Customer Curves function to view the whole desire frequency spectrum, as shown in Fig. 18. You could refer to the video (video8-use_customer_curve.mp4) for demonstration. The frequency is displayed in log scale in x-axis. You could get an idea how the curve looks like.



Customer Curves function

Customer Curves function

Fig. 18

5.3.16 Make use of the frequency sweep function, set frequency function and voltage (P-P, peak to peak) information as shown in Fig. 17, to find the voltage at a desire frequency. For example, we can find out what measuring voltage in Channel-B at 2.01 kHz. You could refer to the video (video9-measuring_voltage_at_a_frequency.mp4).

5.3.17 Find the frequency with the maximum output waveform magnitude (peak to peak). This is the center frequency of your filter. Compare the value with your simulation in lab 5a, Make adjustment of resistor and capacitor values if necessary.

Q1. Find the center frequency of the high frequency band-pass filter. ______________

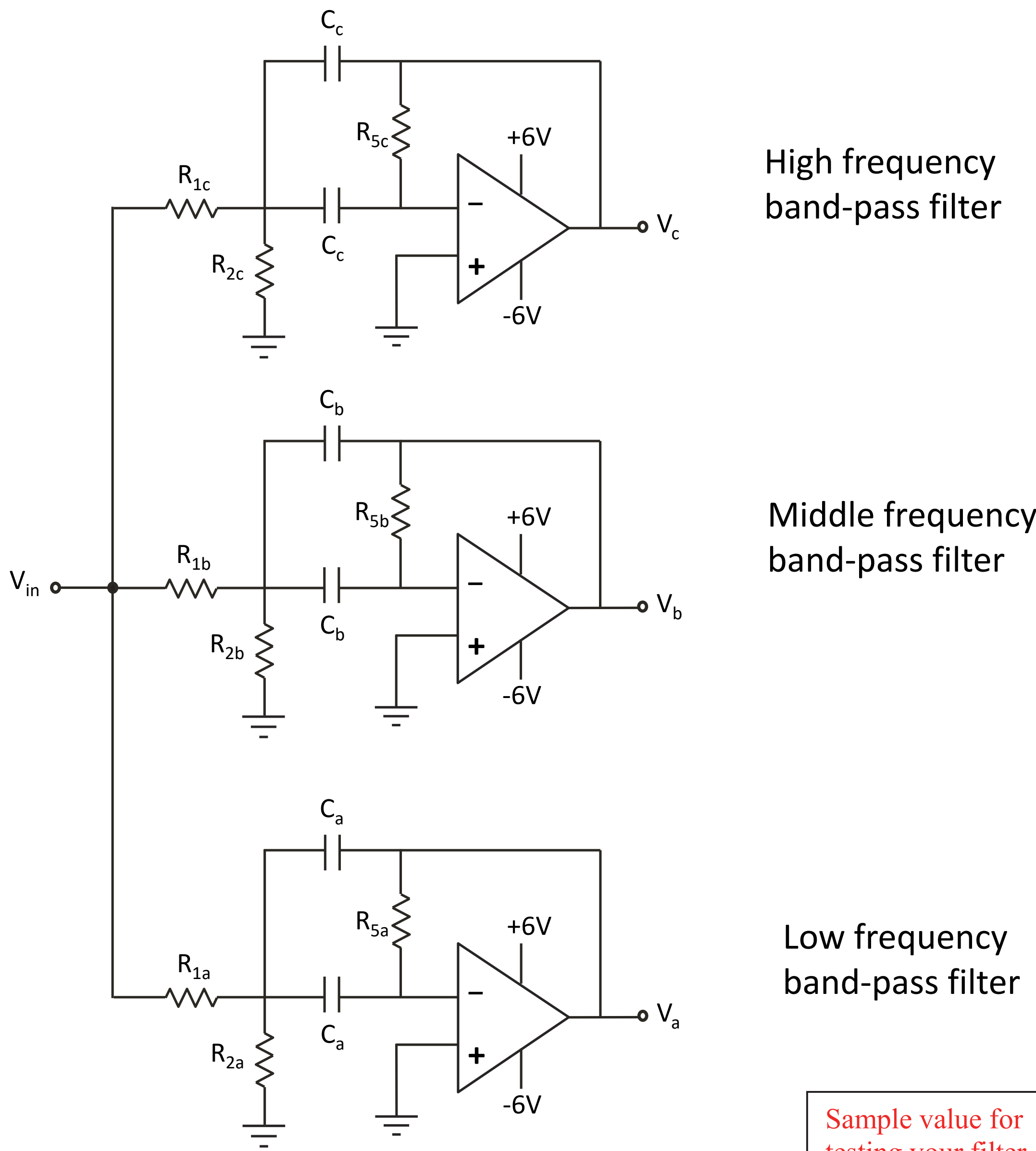
5.3.18 Measure the gain of the filter at the center frequency ($Gain = \frac{V_{out}\,(peak\ to\ peak)}{V_{in}\,(peak\ to\ peak)}$).

Q2. Find the gain of the high frequency band-pass filter at the center frequency. ________

5.3.19 Measure the gain of the filter at one decade below the center frequency of the filter (e.g. if the center frequency of the filter is 8.1kHz, the frequency at one decade below is 0.81 kHz. You then need to find the gain (Vout/Vin) at 0.81 kHz)

Q3. Find the gain of the high frequency band-pass filter at one decade **below** the center frequency. ________

5.3.20 Use the value of the R_{1b}, R_{2b}, R_{5b}, C_b for middle frequency band-pass filter and use the value of R_{1c}, R_{2c}, R_{5c}, C_c for low frequency band-pass filter obtained in Lab 5a simulation. Connect the middle and low frequency band-pass filter circuit as shown in Fig. 19, and put all the components on the breadboard as shown in Fig. 20. For simplicity, only one opamp is used in each LM324 for each band-pass filer.



Sample value for testing your filter circuit

R1 = 100k ohm
R2 = 300k ohm
R5 = 33k ohm
C = 680p F

Fig. 19

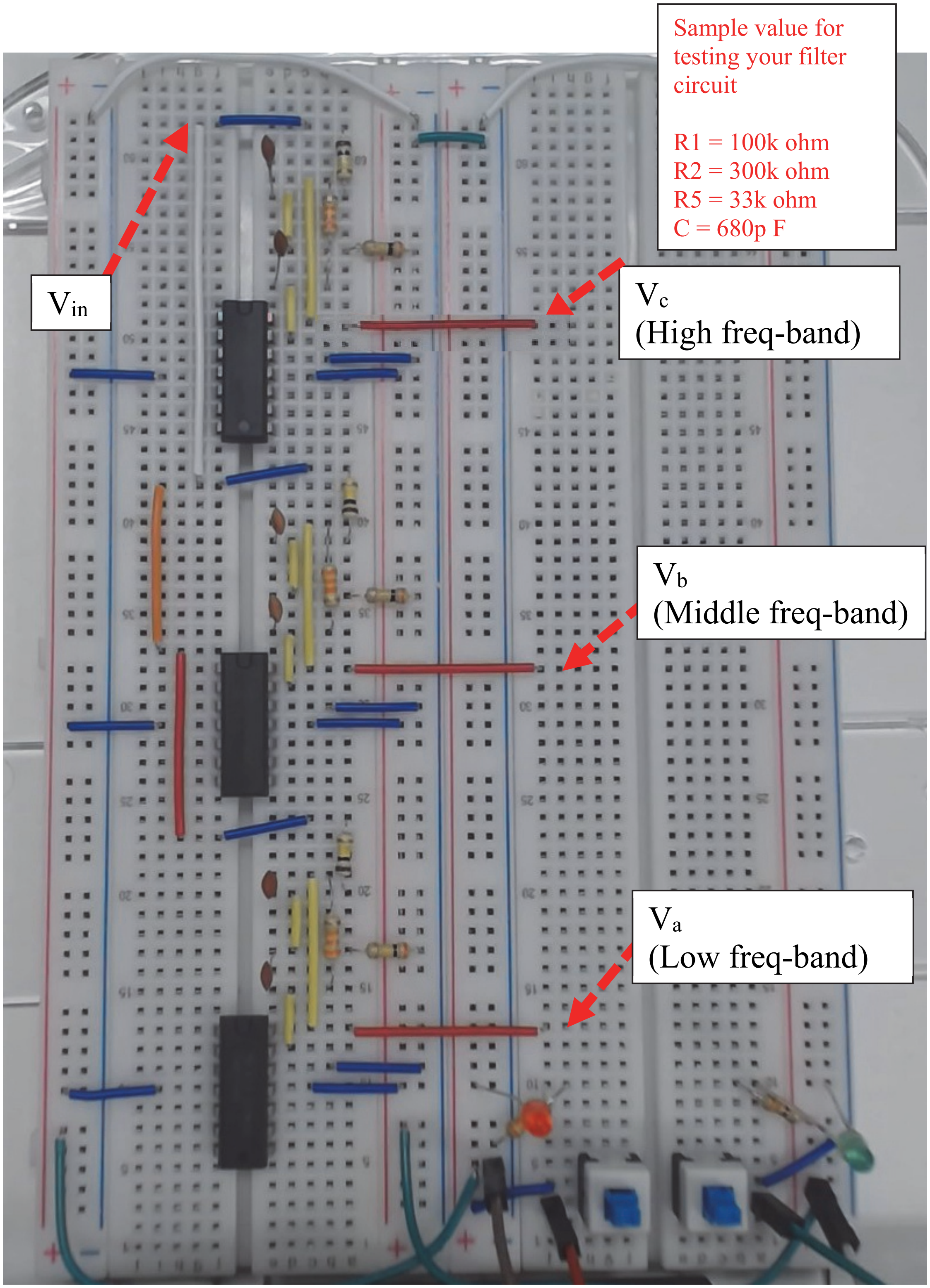

Sample value for testing your filter circuit
R1 = 100k ohm
R2 = 300k ohm
R5 = 33k ohm
C = 680p F
Vin
Vc
(High freq-band)
Vb
(Middle freq-band)
Va
(Low freq-band)

Fig. 20

5.3.21 Repeat the same procedure with other 2 band-pass filer (middle frequency band-pass filer and low frequency band-pass filter. Again, compare the value with your simulation in lab 5a, Make adjustment of resistor and capacitor values if necessary.

Q4. Find the gain of the middle frequency band-pass filter at the center frequency. _____

Q5. Find the gain of the middle frequency band-pass filter at one decade **below** the center frequency. ________

Q6. Find the gain of the low frequency band-pass filter at the center frequency. _____

Q7. Find the gain of the low frequency band-pass filter at one decade **above** the center frequency. ________

5.4 Characterize the Audio Equalizer

Use the value of the R_m, R_G, VR_1, VR_2, and VR3. Connect the equalizer circuit as shown in Fig. 21, and put all the components on the breadboard as shown in Fig. 22.

Connect to the Oscilloscope

5.4.1 Connect the function generator output to Vin
5.4.2 Connect Vin to Channel-A
5.4.3 Connect Vout to Channel-B
5.4.4 Turn all the VRs to the middle position.

Setup frequency Sweet to test the Vout

5.4.5 Set 1kHz, 2 Volt peak to peak, 0 Volt offset, sine wave for Vin.
5.4.6 Adjust the voltage/div scale for Channel-A and for Channel-B, and adjust the sec/div scale for time.
5.4.7 Use frequency sweep function in function generator to change the input signal V_{in}. Set “Start Freq” to 20, “End Freq” to 20000, “Fre span” to 100, and “time span” to 500.
5.4.8 Enable “ScanFreq”, the frequency of the Vin would change from 20 Hz to 20000Hz, with the frequency step of 100Hz for every 500ms.

Adjust different gain for Low frequency band and High frequency band

5.4.9 You could refer to the video (video10-test_with_different_gain.mp4) for 5.4.11 – 5.4.13.
5.4.10 Setup frequency sweep
Start Freq = 20, End Freq = 20000, Fre span = 100, time span = 500.
5.4.11 Enable “ScanFreq”
5.4.12 During frequency sweeping, adjust the VR_1 (High frequency band), VR_2 (Middle frequency band), and VR_3 (Low frequency band) one at a time, you should be able to see changes in Vout (Channel-B).
5.4.13 In the low frequency range, V_{out} vary significantly when the VR_3 (low frequency band) is turned. In the high frequency range, Vout vary significantly when the VR_1 (high frequency band) is turned. Show this to the TA.

Q8. Ask the TA to check/test your equalizer. ___________

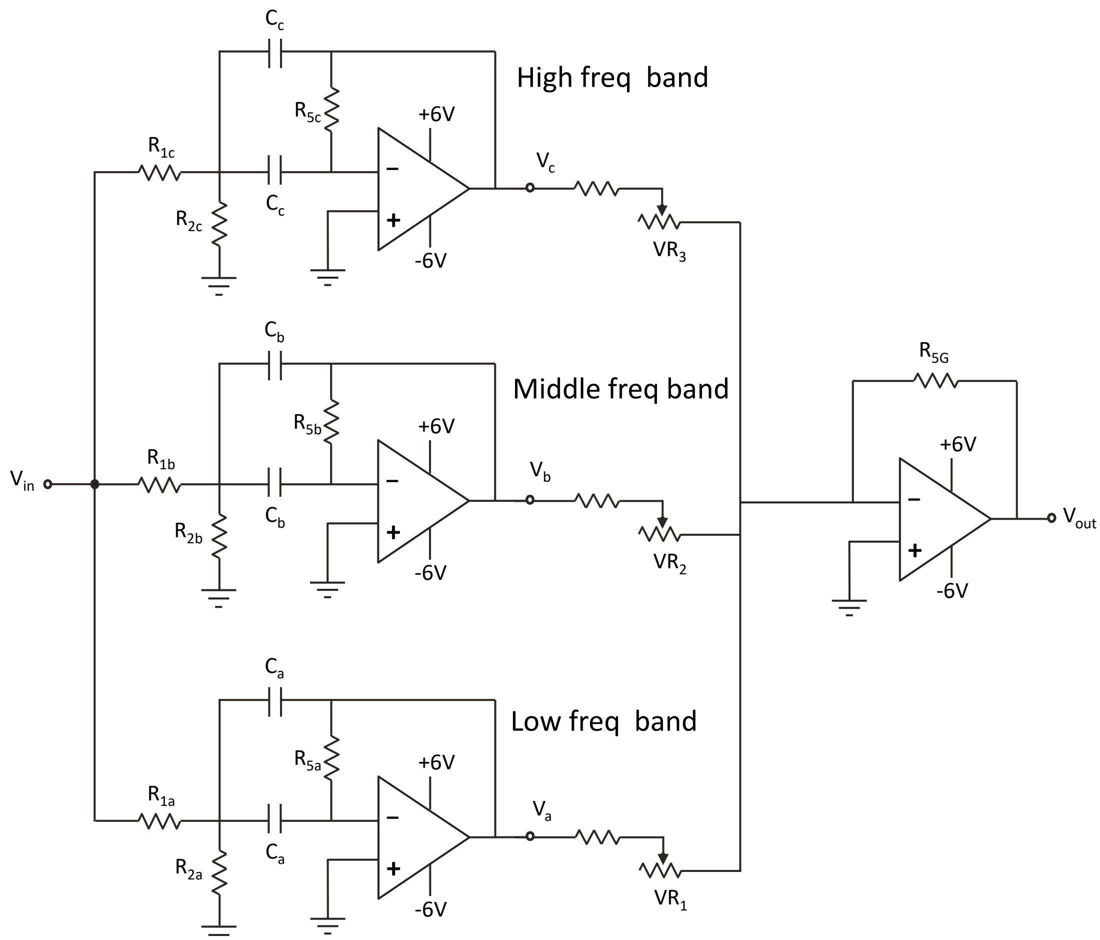

C_c
High freq band
R_{5c}
+6V
R_{1c}
V_c
C_c
R_{2c}
-6V
VR_3
C_b
R_{5G}
Middle freq band
R_{5b}
+6V
+6V
R_{1b}
V_b
V_{in}
C_b
V_{out}
R_{2b}
-6V
VR_2
-6V
C_a
Low freq band
R_{5a}
+6V
R_{1a}
V_a
C_a
R_{2a}
-6V
VR_1

Fig. 21

WARNING: You should use your simulated result in lab 5a for resistor and capacitor values.

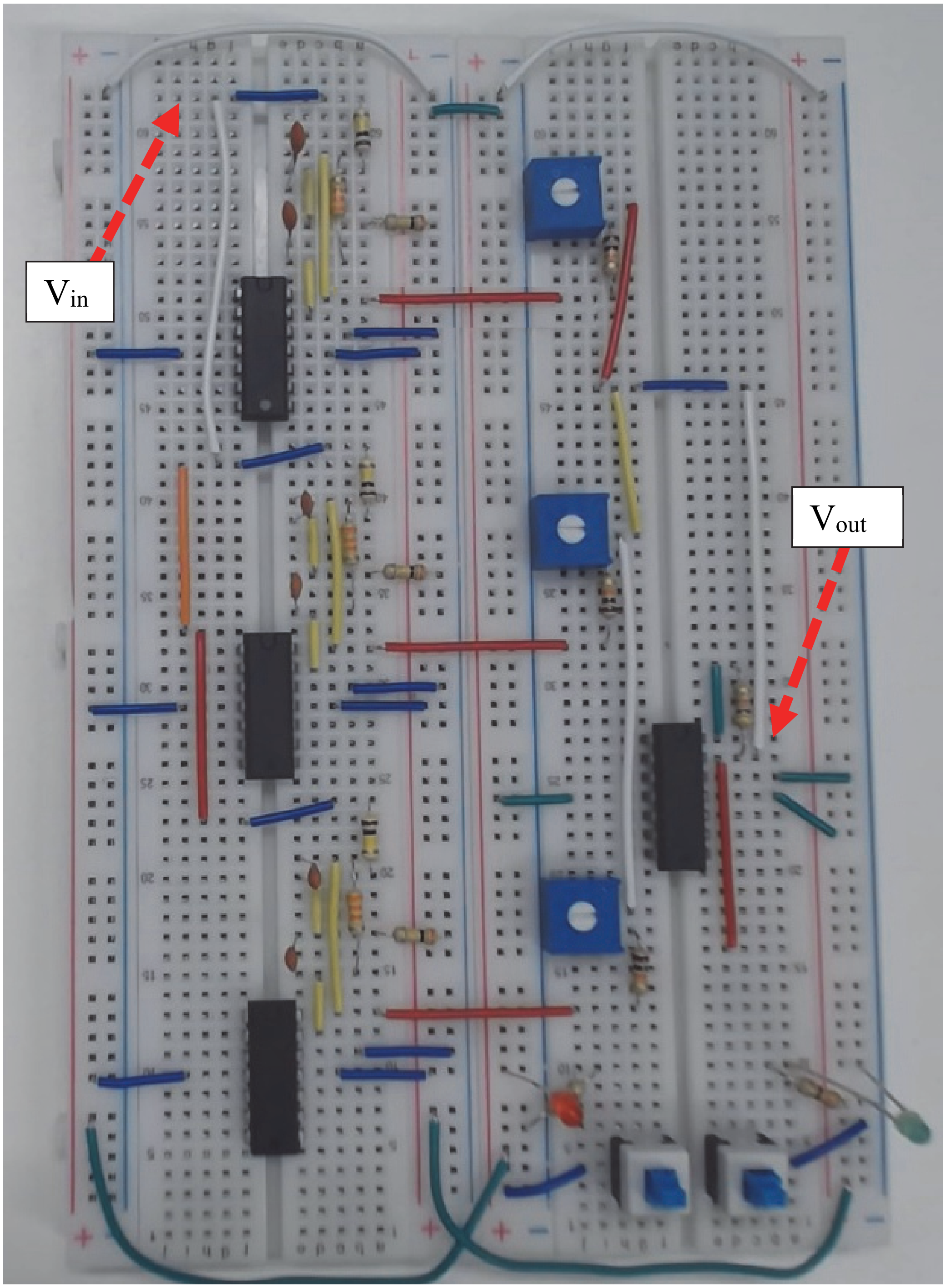


Fig. 22

Measure the frequency response of the equalizer

5.4.14 Set 1kHz, 2 Volt peak to peak, 0 Volt offset, sine wave for V_{in}.

5.4.15 Measure the magnitude of the output waveform and calculate the gain at 80 Hz. ($Gain = \frac{V_{out}\,(peak\ to\ peak)}{V_{in}\,(peak\ to\ peak)}$).

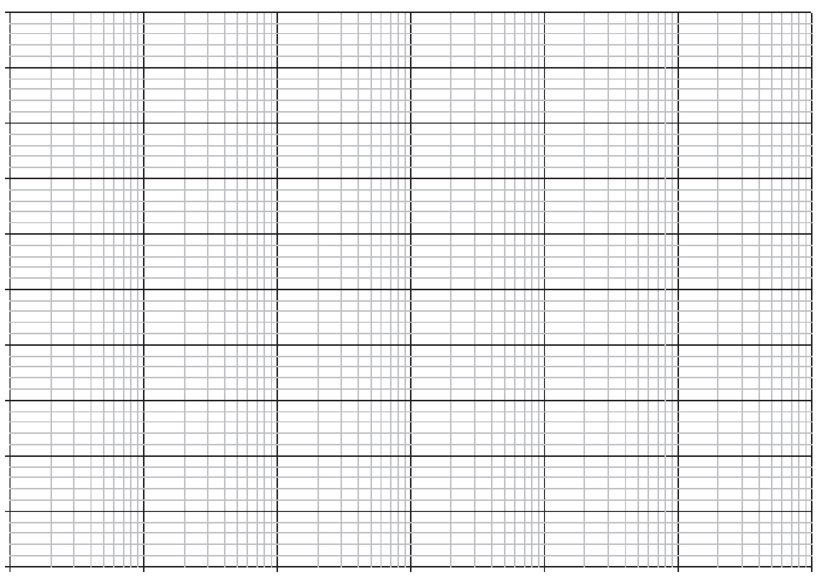
5.4.16 Increase the frequency to 100, 200, 500, 800, 1k, 2k, 5k, 8k, 10k, 20k, 50k, 80k Hz and calculate the gain of the equalizer at these frequencies.

Q9. Measure the magnitude of different frequency, and calculate the gain.

Freq(Hz)	80	100	200	500	800	1k	2k	5k	8k	10k	20k	50k	80k
Vout (V)													
Gain (Vout/Vin)													

5.4.17 Plot the frequency response of the equalizer in the semi-log graph (x-axis in logarithmic scale, y-axis in linear scale). Compare the frequency response with your simulation in the lab5a.

Q10. Plot the frequency response of the equalizer in the semi-log graph. (x-axis (freq) in logarithmic scale, y-axis (gain)in linear scale.)



6. Appendix

Available Standard Resistance Values of 5%-tolerance resistors (1/4W) in the component box.

1 Ω x 10 pcs	10 Ω x 10 pcs	20 Ω x 10 pcs
33 Ω x 10 pcs	47 Ω x 10 pcs	68 Ω x 10 pcs
75 Ω x 10 pcs	82 Ω x 10 pcs	100 Ω x 10 pcs
150 Ω x 10 pcs	200 Ω x 10 pcs	220 Ω x 10 pcs
270 Ω x 10 pcs	300 Ω x 10 pcs	330 Ω x 10 pcs
470 Ω x 10 pcs	510 Ω x 10 pcs	680 Ω x 10 pcs
750 Ω x 10 pcs	820 Ω x 10 pcs	910 Ω x 10 pcs
1 kΩ x 10 pcs	1.5 kΩ x 10 pcs	2k Ω x 10 pcs
2.2 kΩ x 10 pcs	3.3 kΩ x 10 pcs	4.7 kΩ x 10 pcs
5.1 kΩ x 10 pcs	6.8 kΩ x 10 pcs	10 kΩ x 10 pcs
20 kΩ x 10 pcs	33 kΩ x 10 pcs	47 kΩ x 10 pcs
51 kΩ x 10 pcs	68 kΩ x 10 pcs	91 kΩ x 10 pcs
100 kΩ x 10 pcs	200 kΩ x 10 pcs	220 kΩ x 10 pcs
300 kΩ x 10 pcs	330 kΩ x 10 pcs	470 kΩ x 10 pcs
510 kΩ x 10 pcs	680 kΩ x 10 pcs	750 kΩ x 10 pcs
820 kΩ x 10 pcs	910 kΩ x 10 pcs	1 MΩ x 10 pcs

Available capacitance Values of ceramic capacitor in the component box

10 pcs for each value

100 (10 pF)	200 (20 pF)	220 (22 pF)	300 (30 pF)	101 (100 pF)
221 (220 pF)	331 (330 pF)	471 (470 Pf)	102 (1000 pF)	222 (2200 pF)
332 (3300 pF)	472 (4700 pF)	103 (10 nF)	223 (22 nF)	333 (33 nF)
473 (47 nF)	104 (100 nF)	224 (220 nF)	334 (330 nF)	474 (470 nF)
105 (1 uF)	225 (2.2 uF)	106 (10 uF)		

Available variable-resistor (VR) in the component box

2k x 2	10k x2	100k x4

Available operational-amplifier in the component box

LM324 x 5 (opamp)