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



# LAB 5a – Audio Equalizer (PSpice Simulation)

## 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. Four 741 Op Amp ICs
b. Dual power supply
c. Waveform generator
d. Dual channel oscilloscope

## 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. Figure 1 below shows one implementation of the audio equalizer system with three frequency bands and its frequency characteristic.

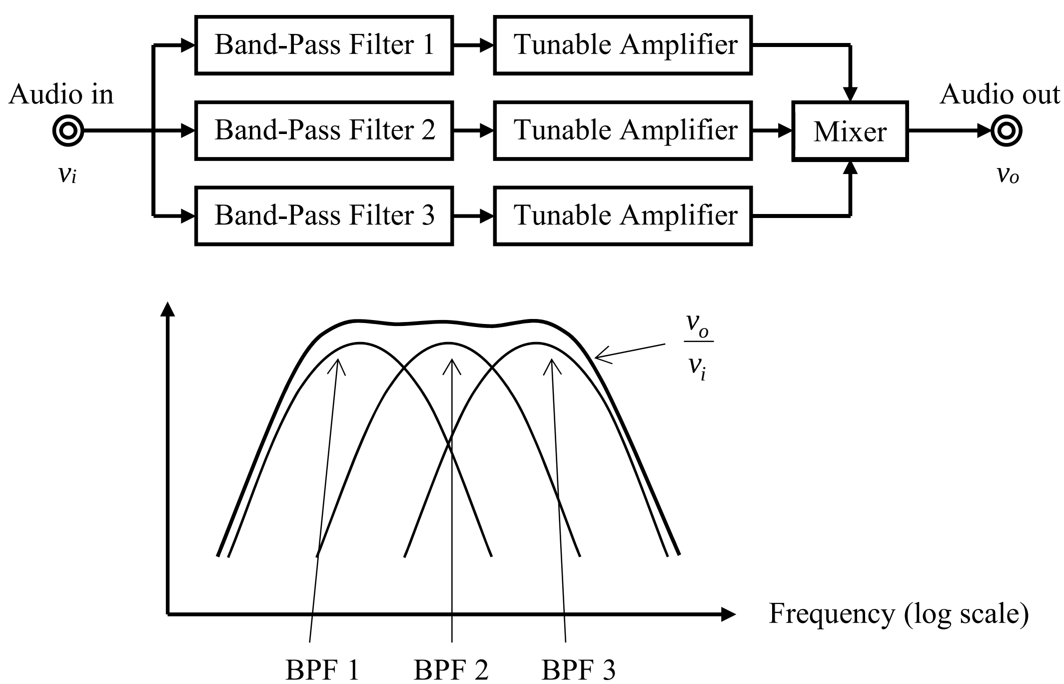


Figure 1: An audio equalizer system

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 Figure 2 which uses one operational amplifier and five resistors and capacitors.

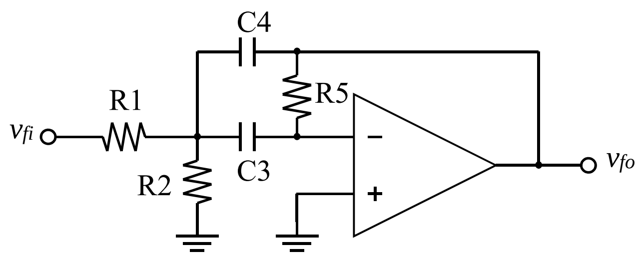


Figure 2: A band-pass filter

The voltage transfer function is given by

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

In terms of the band-pass filter function,

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

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

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

where $H_o$ is the gain of the pass-band filter at the center frequency $\omega_o$ 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 Figure 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.

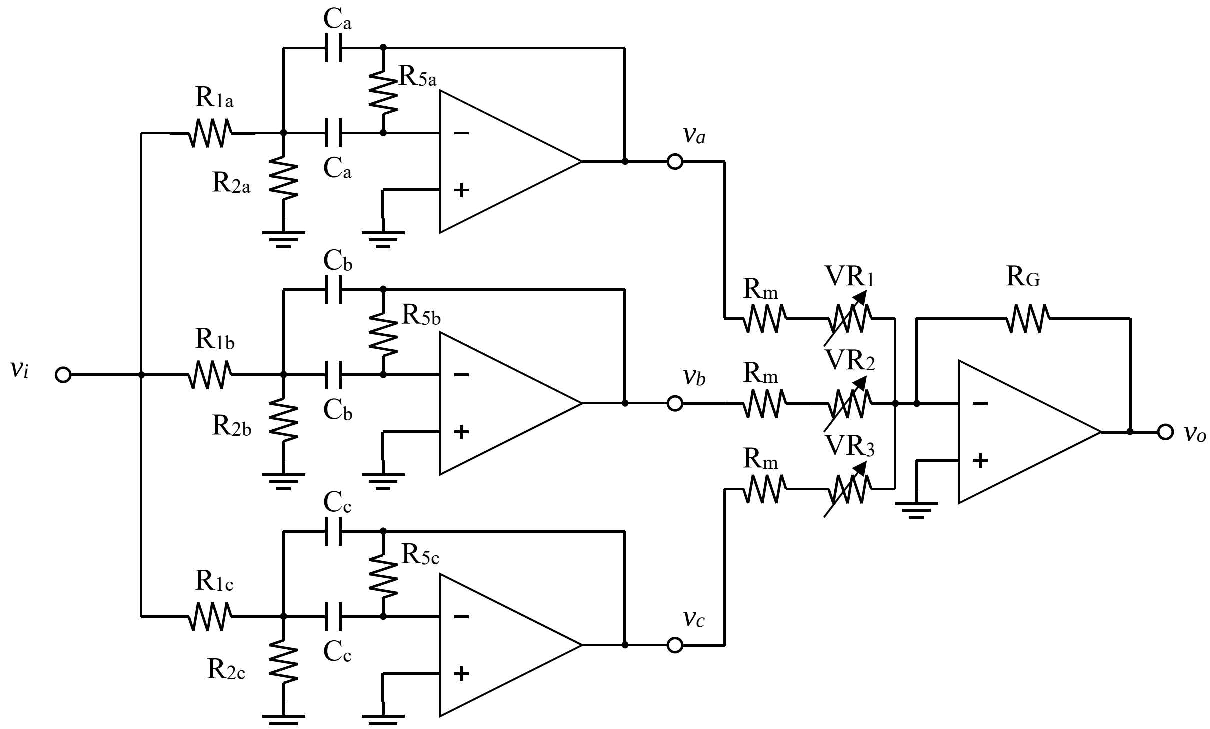


Figure 3: A 3-band equalizer

where $C_a$ is for lower frequency, $C_b$ is for middle frequency, and $C_c$ is for higher frequency.

## 4. Experiment

You are required to design your own equalizer. You need to determine the center frequencies and the Q values of the band-pass filters. You may consider the lower frequency filter corresponds to the Bass of your equalizer, the middle frequency is the vocal frequency and the higher frequency filter is the Treble of your equalizer. For your information, human can hear around 20 Hz to 20 kHz. Human voice is between 80 Hz to 800 Hz and piano ranges from 30 Hz to 4 kHz.

In the other words, you need to find out the resistor and capacitor values of your equalizer. Assume there is only one turn 100 kΩ VRs are available in the laboratory. Please note that there are only a certain standard resistance and capacitor values available in your lab kit, as shown in 5-Appendix. You should check it.

You should use the PSpice circuit simulator (PSpice student release) to simulate your equalizer to obtain the frequency characteristic to confirm the resistor and capacitor values. You should refer to the session 4.4.6-4.4.8 of the lab#2 manual for reviewing how to obtain the frequency characteristic (20Hz-20KHz). In PSpice, r is resistor, c is capacitor, R_var is variable resistor (VR), and opamp is operational amplifier.

**Q1. Write down all the calculated component values.**

| | | | |
|---|---|---|---|
| $R_{1a}$ | ____________ | $VR_1$ | 100K Ω |
| $R_{2a}$ | ____________ | $VR_2$ | 100K Ω |
| $R_{5a}$ | ____________ | $VR_3$ | 100K Ω |
| $R_{1b}$ | ____________ | $R_{1c}$ | ____________ |
| $R_{2b}$ | ____________ | $R_{2c}$ | ____________ |
| $R_{5b}$ | ____________ | $R_{5c}$ | ____________ |
| $R_G$ | ____________ | $R_m$ | ____________ |
| $C_a$ (lower freq) | ____________ | $C_b$ (middle freq) | ____________ |
| $C_c$ (higher freq) | ____________ | $f_{o\_Lower}$ | ____________ |
| $f_{o\_Middle}$ | ____________ | $f_{o\_Higher}$ | ____________ |

**Q2. Show the simulated frequency characteristic of your equalizer to TA.**

**Q3. Capture the simulated frequency characteristic of your equalizer.**

## 5. 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)