Assignment Report

TERM: **Autumn 2022**

Module: **EE1618 Devices and Circuits**

CLASS: 34092102

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December 2022

1. Introduction

1.1. Aims

To review the Devices and Circuits we learned before. Further understand passive circuits, passive and active filters, some passive and active components. To solve some basic circuits problems through the knowledge we learned before. In addition, learn to verify theoretical analysis through circuit simulation.

To review the Devices and Circuits we learned before. Further understand passive circuits, passive and active filters, some passive and active components. **In PART 1**, use circuit theory and network analysis we learned before to solve the question 1~9. This part can demonstrate our ability to analyze circuits and compute. **In PART 2**, use PSPICE OrCad to simulate the passive and active filters, verify theoretical results through simulation results. Finally, give corresponding solutions with technical writing.

1.2. Objectives

a) To review the contents of EE1618 Devices and Circuits, which include some circuits analysis methods and knowledge of analog circuits.

b) To do some exercise and demonstrate what we have learned in this semester. It can help me further understand some knowledge points.

c) To solve some circuits problems by myself.

d) To simulate the circuits. Compare the simulation results with the theoretical values, verify and discuss the results.

e) Analysis the result, draw the conclusions by analyzing the simulation.

2. PART1: Passive Circuits

2.1.

$$Q = It = 3A \cdot 300s = 900C.$$

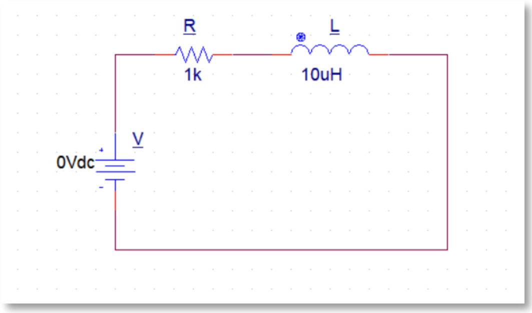
2.2.

1) The definition of a passive circuit:

Circuits that do not include diodes, triodes, integrated circuits, and other components, but only resistors (R), capacitors (C), inductors (L) and other components are passive circuits.

2)

2.3.



This is the circuit diagram.

$$V_L = L \cdot \frac{di_L}{dt}$$

Use KVL:

$$E = V_R + V_L$$

$$E = iR + L \cdot \frac{di_L}{dt}$$

$$E - iR = L \cdot \frac{di_L}{dt}$$

$$\frac{dt}{L} = \frac{di}{E - iR}$$

$$\int \frac{dt}{L} = \int \frac{di}{E - iR}$$

$$\frac{t}{L} = -\frac{1}{R} ln(E - iR) + C$$

If $t=0$, $i=0$

$$C = \frac{1}{R} lnE$$

Therefore, the formula can be written as

$$\frac{t}{L} = -\frac{1}{R} ln(E - iR) + \frac{lnE}{R}$$

$$-\frac{tR}{L} = ln(\frac{E - iR}{E})$$

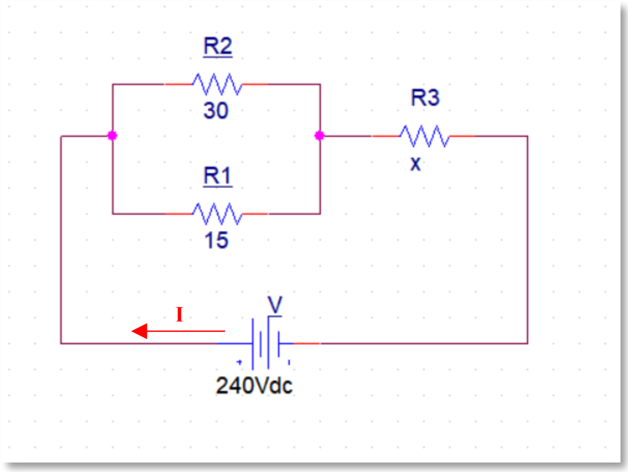
$$e^{-\frac{tR}{L}} = \frac{E - iR}{E}$$

$$(1 - e^{-\frac{tR}{L}}) \cdot \frac{E}{R} = i$$

Let $\tau = \frac{L}{R}$

$$\boldsymbol{i = (1 - e^{-\frac{t}{\tau}}) \cdot \frac{E}{R}}$$

2.3.



$$I = \frac{P}{V} = 15A$$

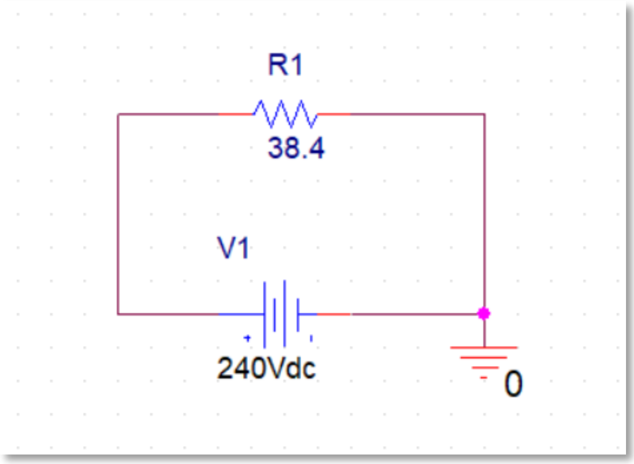
$$R_1 = 15\Omega, R_2 = 30\Omega$$

$$R_T = R_1 \mid\mid R_2 + R_x = \frac{V}{I} = 16\Omega$$

$$\boldsymbol{R_x = 6\Omega}$$

2.4.

a) ***In section 1***, the electric heater is connected to a constant 240V voltage source and absorbs 1500W.



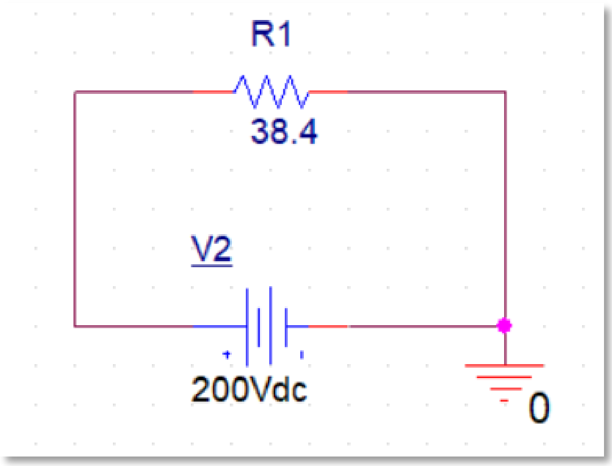
Due to the formula $P = \frac{V^2}{R}$.

In this section, $P_1 = 1500\,W, V_1 = 240\,V$.

$$\boldsymbol{R_1 = \frac{{V_1}^2}{P_1} = \frac{(240\,V)^2}{1500\,W} = 38.4\Omega}$$

Therefore, the resistance of the heater is 38.4Ω.

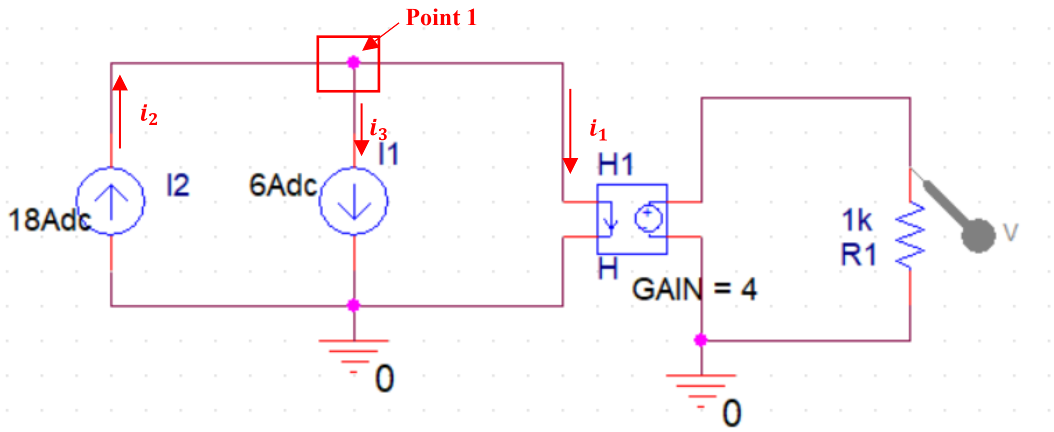
b) ***In section 2***, the heater is subsequently connected to a 200V voltage source.



In this section, $V_2 = 200\,V$. R_1 remains unchanged.

$$\boldsymbol{P_2 = \frac{{V_2}^2}{R_1} = \frac{(200\,V)^2}{38.4\Omega} = 1041.67\,W}$$

2.5.



Apply KCL to **Point 1**: $i_2 = 18A, i_3 = 6A$.

$$i_2 = i_1 + i_3$$

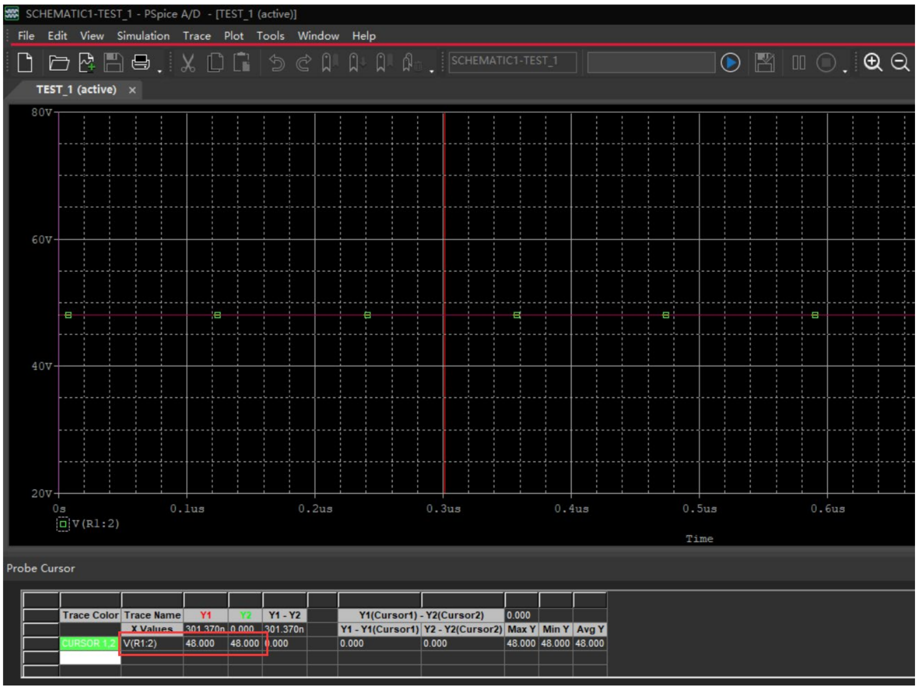
Thus, $i_1 = 12\,A$.

Because the circuit contains a controlled source, and the controlled source is **current-controlled voltage source (CCVS)**. Therefore, the value of CCVS voltage is $\boldsymbol{V_1 = 4i_1 = 48\,V}$.

Apply KVL to the circuit on the right side of CCVS:

$$V_1 - V_2 = 0$$

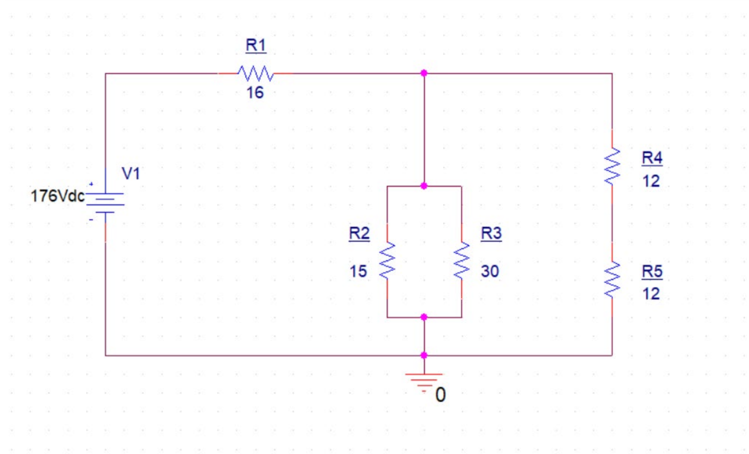
$$\boldsymbol{V_2 = 48V}$$



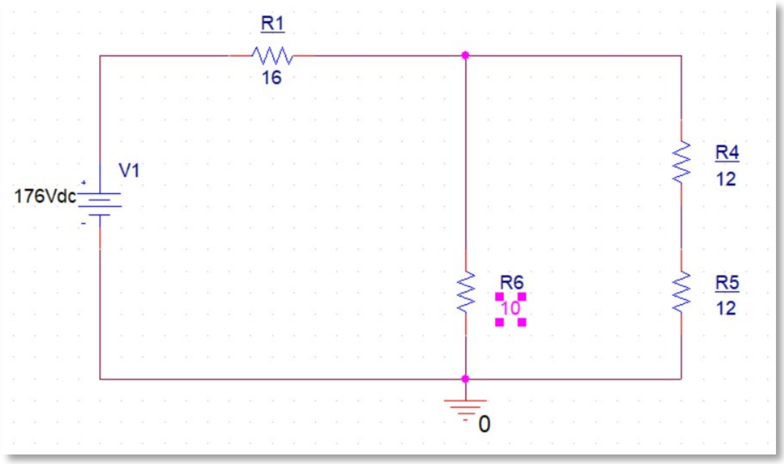
After simulation, I can verify my answer.

2.6.

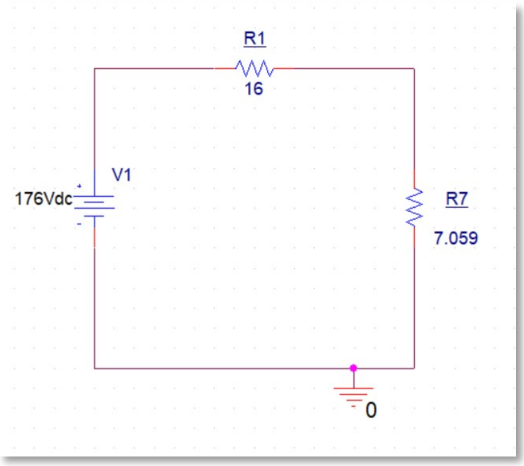
a) Find the power supplied by the voltage source.



To find the power supplied by the voltage source, I need reduced the circuit firstly.



$$R_6 = R_2 \,||\, R_3 = 10\Omega$$



$$R_7 = (R_4 + R_5) \,||\, R_6 = \frac{120}{17}\Omega = 7.059\Omega$$

After reduced the circuit:

$$V_1 = 176\,V$$
$$R_T = R_1 + R_7 = 23.06\Omega$$
$$\boldsymbol{P_1 = \frac{{V_1}^2}{R_T} = 1343.28\,W}$$

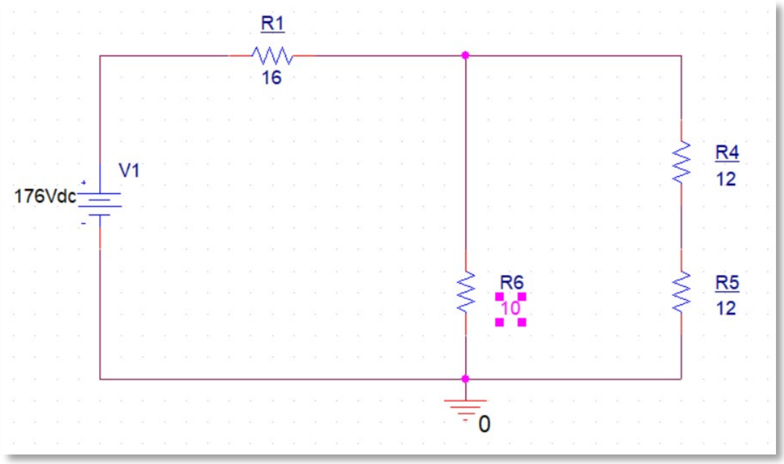
Therefore, the power supplied by the voltage source is **1343.28 W.**

b) ***Find the power absorbed by the*** 30Ω ***resistor (R3).***

In the last section, I reduced the circuit. Now, I need return it.

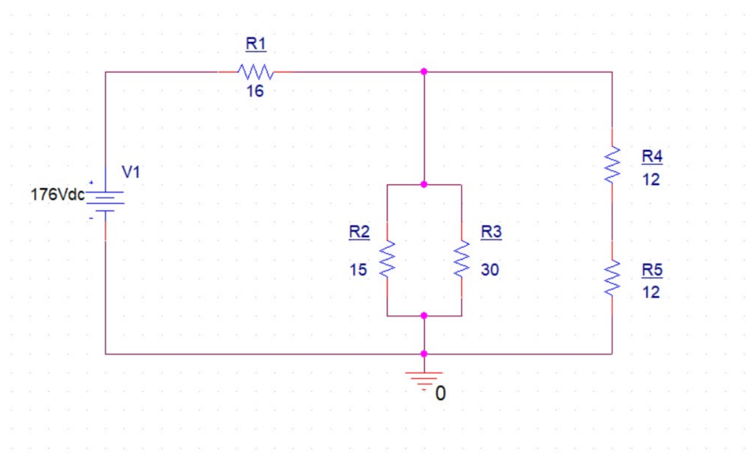
By voltage divider rule:

$$V_{R_7} = \frac{R_7}{R_1 + R_7} \cdot V_1 = 53.88\,V$$



Because R_6 is parallel with R_4 and R_5.

$$V_{R_6} = V_{R_7} = 53.88\ V$$



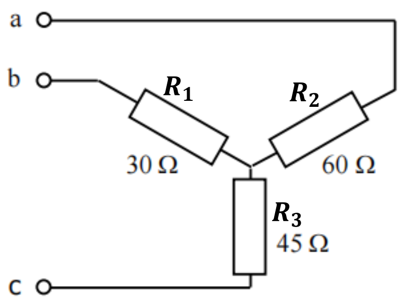
R_2 is parallel with R_3.

$$V_{R_3} = V_{R_6} = 53.88\ V$$

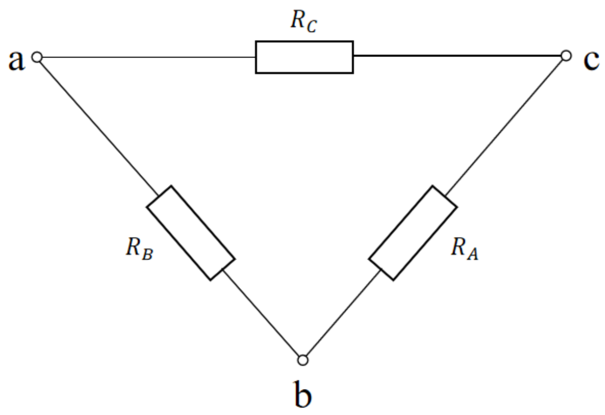
$$\boldsymbol{P_2 = \frac{{V_{R_3}}^2}{R_3} = 96.77\ W}$$

Therefore, the power absorbed by the R3 is **96.77 W.**

2.7.



I set the 30Ω resistance is R_1, 60Ω resistance is R_2 and 45Ω resistance is R_3.

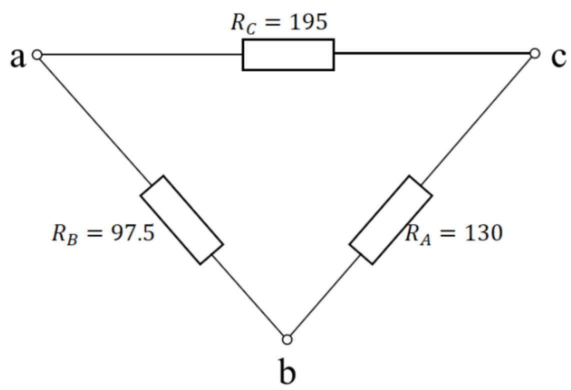


I want to convert the *star* into *delta*, so I draw the initial result diagram and label three resistances R_A, R_B *and* R_C.

$$\boldsymbol{R_C = \frac{R_1R_2 + R_1R_3 + R_2R_3}{R_1} = 195\Omega}$$

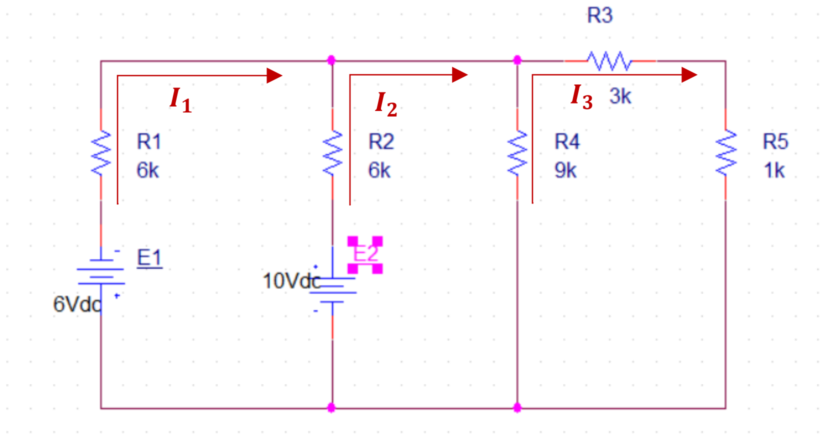
$$\boldsymbol{R_B = \frac{R_1R_2 + R_2R_3 + R_1R_3}{R_2} = 97.5\Omega}$$

$$\boldsymbol{R_A = \frac{R_1R_2 + R_1R_3 + R_2R_3}{R_3} = 130\Omega}$$



This is the result after conversion.

2.8.



Loop 1:

$$-E_1 - I_1R_1 - (I_1 - I_2)R_2 - E_2 = 0$$

Loop 2:

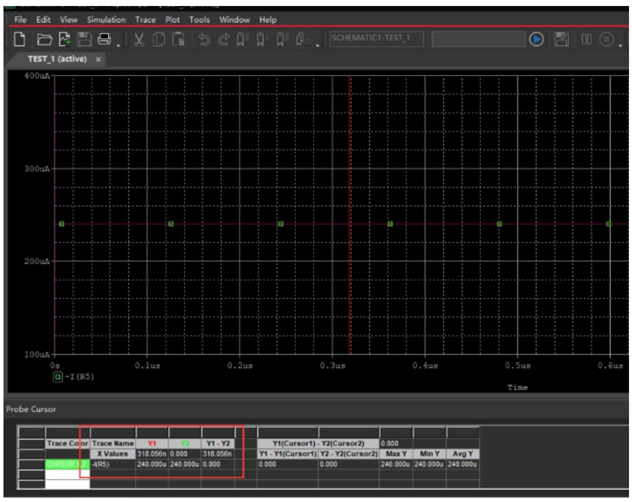
$$E_2 - (I_2 - I_1)R_2 - (I_2 - I_3)R_4 = 0$$

Loop 3:

$$-(I_3 - I_2)R_4 - I_3R_3 - I_3R_5 = 0$$

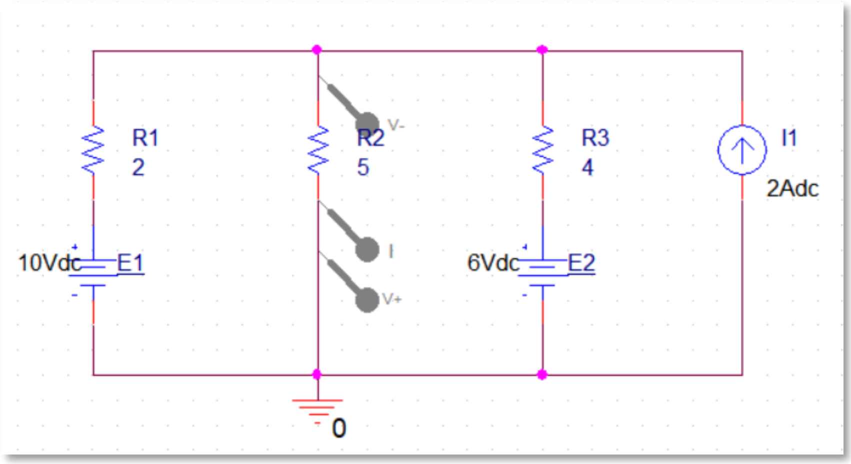
Thus, the solution of I_3 is:

$$I_3 = 0.24\, mA$$

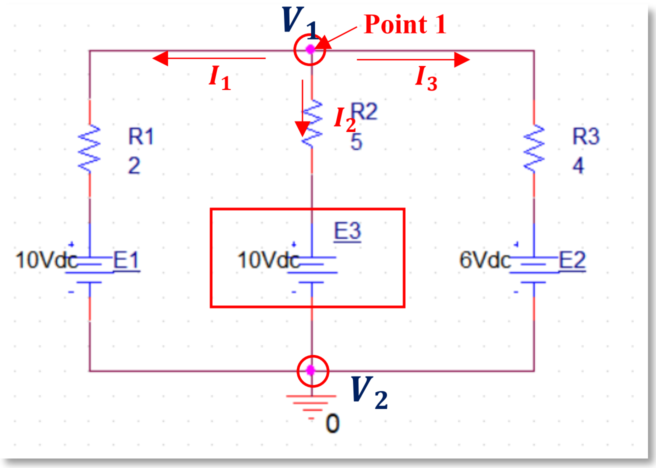


After simulation, I can verify the result is correct.

2.9.



The current source is parallel with a resistance R_2. So, I can convert the current source to voltage source. I set the 5Ω resistance is R_2, and the value of current source $I_1 = 2\ A$.



Because:

$$E = IR$$

Thus, the value of voltage source after conversion is:

$$E_3 = I_1 R_2 = \mathbf{10\ V}$$

I define the current flowing through the resistance R_1 as I_1, the current flowing through R_2 as I_2, the current flowing through R_3 as I_3.

Apply **KCL** to **point 1**:

$$I_1 + I_2 + I_3 = 0$$

$$\boldsymbol{I_1 = \frac{V_1 - 10\Omega - V_2}{2\Omega}}$$

$$\boldsymbol{I_2 = \frac{V_1 - 10\Omega - V_2}{5\Omega}}$$

$$I_3 = \frac{V_1 - 6\Omega - V_2}{4\Omega}$$

Thus, we can give the solution of $V_1 - V_2$.

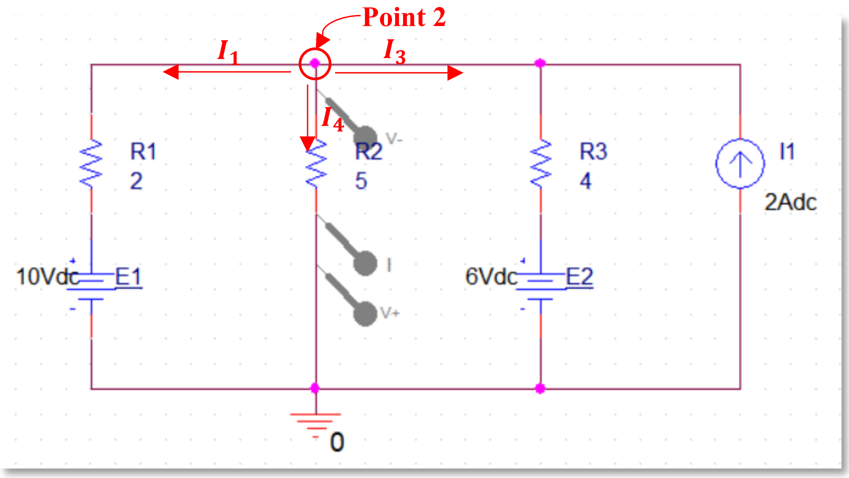
$$V_1 - V_2 = 8.95\ V$$

Then, I can find the value of $I_1\ and\ I_3$.

$$I_1 = \frac{(8.95 - 10)\ V}{2\Omega} = \mathbf{-0.525\ A}$$

$$I_3 = \frac{(8.95 - 6)\ V}{4\Omega} = \mathbf{0.7375\ A}$$

It means the value of I_1 is 0.525 A, the direction has V_1 pointing to V_2. The value of I_3 is 0.7375A, the direction has V_2 pointing to V_1.



Then I return the circuit diagram. Apply **KCL** to **point 2**:

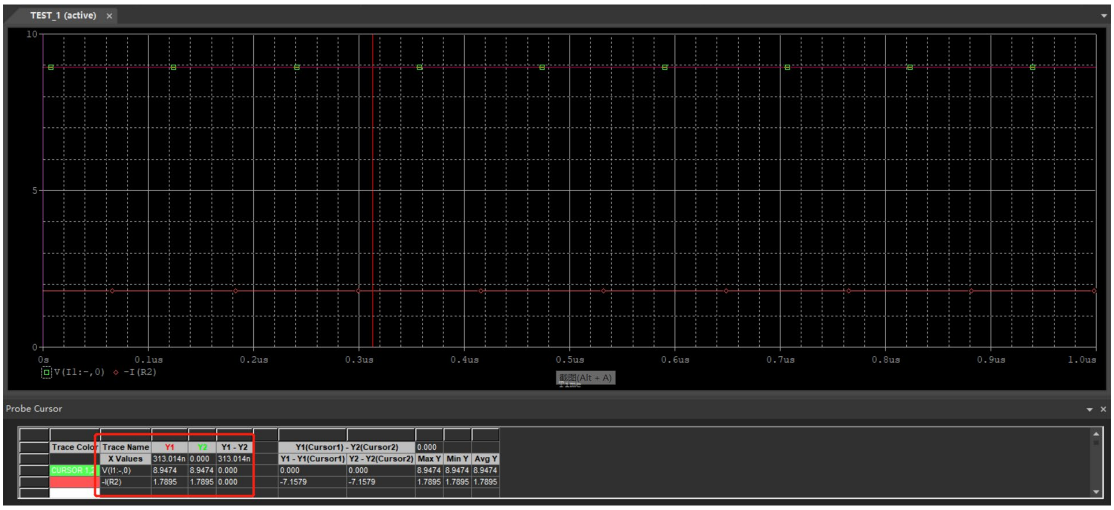
$$I_1 + I_3 - 2A + I_4 = 0$$

Then, I can find the solution of I_4

$$I_4 = 1.7875\ A$$

$$P = {I_4}^2 R_2 = (1.7875A)^2 \times 5\Omega = \mathbf{15.98\ W}$$

Therefore, the power dissipated in the 5Ω is **15.98 W**.



Finally, I simulate the circuit on the PSPICE, the result is verified to be correct.

3. PART2: Passive and Active Filters

3.1. Analysis and simulation Passive RC low-pass filter

a)

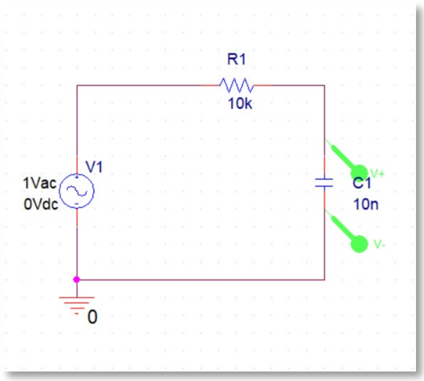


Fig. 1. RC circuit

This is the circuit diagram.

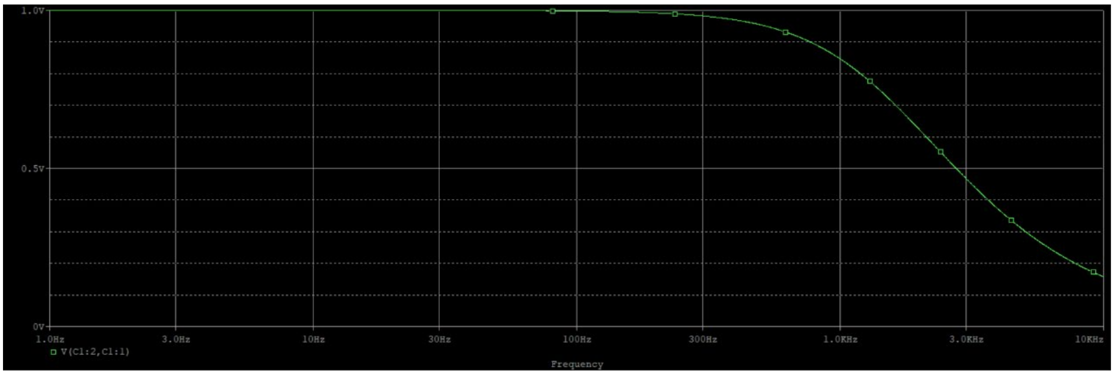


Fig. 2. Frequency performance of the output voltage

This is the diagram of the frequency performance of the output voltage. In the bandwidth, the value of output voltage is 1V, and it is equal to the input voltage.

Therefore, **the voltage gain $A_V = 1$.**

b)

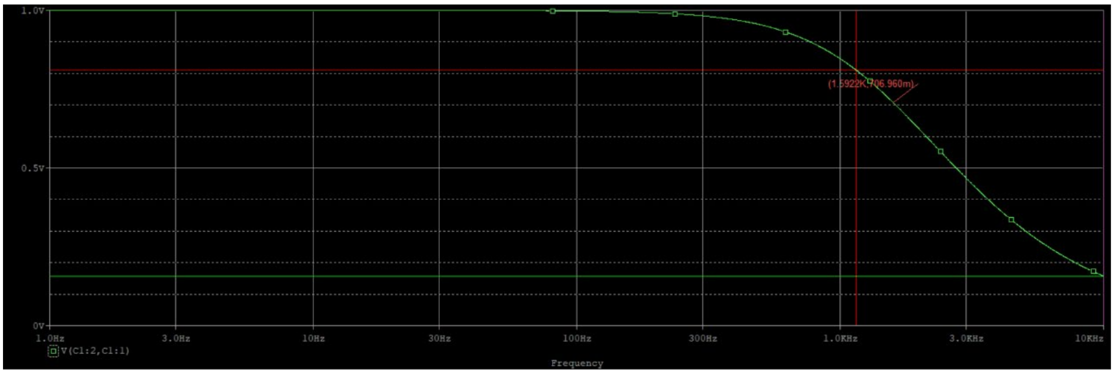


Fig. 3. Cut-off frequency of the output voltage

$$-3dB = 20log_{10}(\frac{V_2}{V_1})$$

The value of voltage $V_1 = V_{max} = 1\ V$, thus, $V_2 = 0.707\ V_{max} = 0.707\ V$.

I change the frequency until the ordinate reaches 0.707V, the corresponding frequency is cut-off frequency. **The value of Cut-off frequency is 1.5922 kHz.**

c)

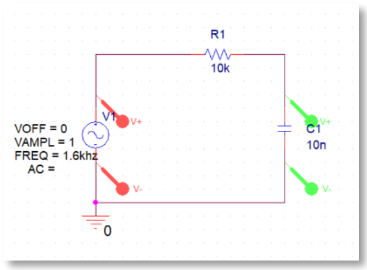


Fig. 4. Phase shift at 1.6 kHz

I change the AC source to sinusoidal signal source. The input signal frequency is a fixed value of 1.6 kHz.

Fig. 5. The waveform of phase shift

The simulation is shown in figure 5. The green line is output voltage, the red line is input voltage. I took the time value corresponding to the lowest point of the two waveforms. The time corresponding to the first wave trough is $\boldsymbol{t_1 = 471.686\ s}$, the time corresponding to the second wave through is $\boldsymbol{t_2 = 546.636\ s}$. Due to the frequency of source is 1.6kHz, the period T=0.625ms. Set θ as phase shift. Phase shift means the phase difference between the output voltage and the input voltage.

$$\frac{\boldsymbol{t_1 - t_2}}{\boldsymbol{T}} = \frac{\boldsymbol{\theta}}{\boldsymbol{2\pi}}$$

Thus, the phase shift $\boldsymbol{\theta = -0.754}$. In addition, from the figure 5, I can find that the phase of input voltage is lead to output voltage. Figure 6 shows the rotation vector diagram of input voltage and output voltage. Therefore, the phase shift is a negative value.

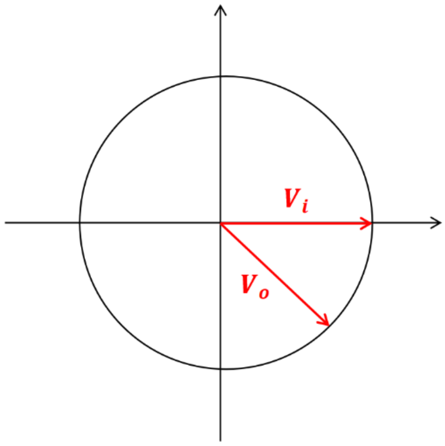


Fig. 6. Rotation vector diagram

d)

According to the theoretical calculation. When $R = X_c$, the corresponding frequency is cut-off frequency.

$$R = X_c = \frac{1}{2\pi f c}$$

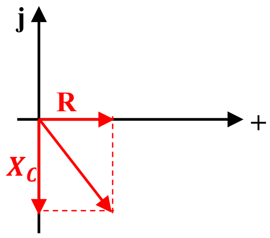
$$f = \frac{1}{2\pi RC} = \boldsymbol{1.5915\ kHz}$$

In part b), the cut-off frequency is 1.5922 kHz. It is remarkably like the result calculated in this part d). Therefore, it can be proved that the cut-off frequency meets the scientific expectation.

Next, verify the part c). At 1.6 kHz, $f = 1.6\ kHz, C = 10\ nF$.

$$X_c = \frac{1}{2\pi f c} = 9.95 \times 10^3\ \Omega$$

Because this is the low-pass filter. The right figure shows the relationship between $X_c\ and\ R$.



$$\frac{V_0}{V_i} = \frac{X_C\angle -90°}{R - jX_C}$$

$$= \frac{X_c\angle - 90°}{\sqrt{R^2 + {X_c}^2}\angle - arctan\left(\frac{X_c}{R}\right)}$$

$$= \frac{X_c}{\sqrt{R^2 + {X_c}^2}} \angle -90° + arctan\left(\frac{X_c}{R}\right)$$

$$= \frac{X_c}{\sqrt{R^2 + {X_c}^2}} \angle -arctan\left(\frac{R}{X_c}\right)$$

Therefore, the phase shift or the phase angle is $\boldsymbol{\angle - arctan\left(\frac{R}{X_c}\right)}$.

$$\boldsymbol{\theta = \angle - arctan\left(\frac{R}{X_c}\right) = -0.788}$$

$R = 10\ k\Omega, X_c = 9.95 \times 10^3\ \Omega$. Thus, the phase shift is -0.788. In the part c), the lab result is -0.754, it is very similar to the theoretical results. Therefore, it can be proved that the phase shift meets the scientific expectation.

e)

The circuit can be used as a low-pass filter. It allows the passage of low frequency signals but attenuates the passage of signals whose frequency is higher than the cut-off frequency.

Low- pass filter can be used in rectifier to help convert DC voltage to AC voltage. The electronic low-pass filter is used to drive subwoofer and other types of loudspeakers and block the treble beat that they cannot effectively transmit. The radio transmitter uses a low-pass filter to block harmonic emissions that may cause interference with other communications.

In some cutting-edge technologies, low-pass filters also have good applications. A reconfigurable low-pass filter that dissipated very low power with dynamic threshold metal–oxide–semiconductor technique for Bluetooth low energy and biomedical applications of new portable Internet-of-Things devices [2].

f)

There are 3 factors that may contribute to possible measurement errors in a practical environment.

1) Circuit Tolerance

In the process of equipment development, the imperfect circuit design will cause the parameter drift of components, which will lead to the quality problem of components. Circuit tolerance refers to the difference between the design value and the true value of components. For instance, if the tolerance of a resistance is 5%, the design value of this resistance is 100Ω. The true value of this resistance is $100\,\Omega \times (1 \pm 5\%) = 95\,\Omega \sim 105\,\Omega$. This tolerance can lead measurement error in circuit. After analysis, there are three main factors that cause component parameter drift: component production, environmental impact, and degradation effect [3].

2) Temperature

Temperature is still an important factor causing errors. If the temperature is too high, the value of resistance can be affected. Thus, the measurement of cut-off frequency and phase shift may be affected.

3) Reading Error

The reading will produce certain error, so there will be a certain gap between the measured result and the true value. For instance, in the PSPICE simulation, it is difficult to move the mouse to the position exactly corresponding to the corresponding voltage, which will cause errors in the obtained cut-off frequency.

3.2. Analysis and simulation of Passive RC high-pass filter

a)

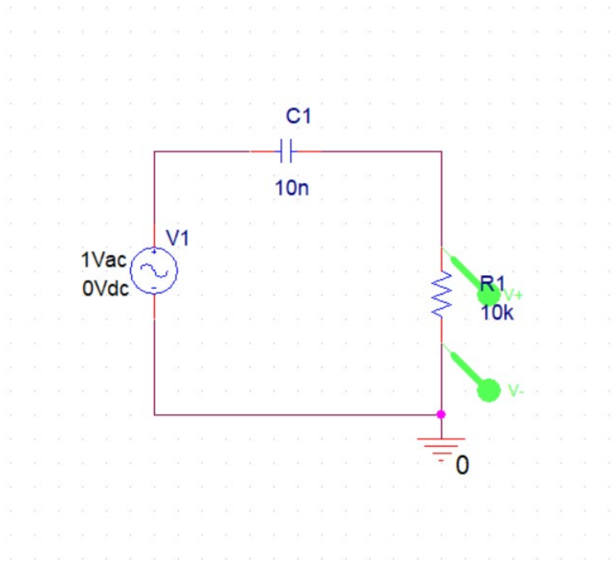


Fig. 7. RC circuit

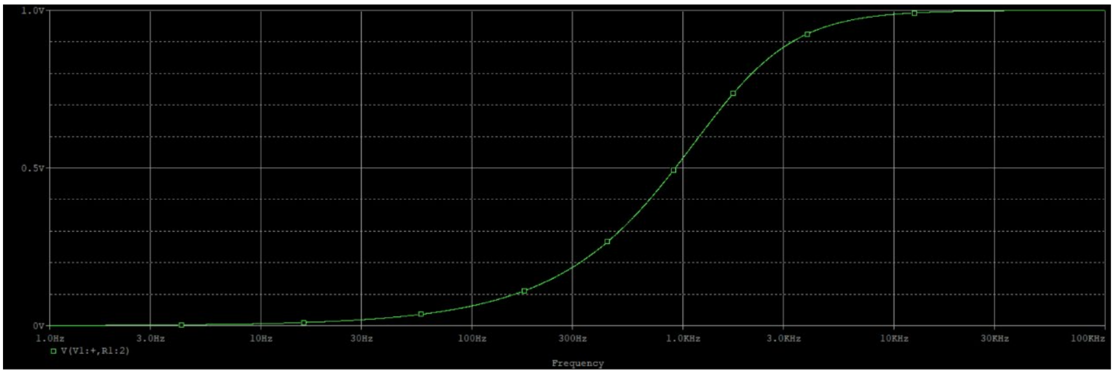


Fig. 9. Frequency performance of the output voltage

This is the diagram of the frequency performance of the output voltage. In the bandwidth, the value of output voltage is 1V, and it is equal to the input voltage.

Therefore, **the voltage gain $A_v = 1$.**

b)

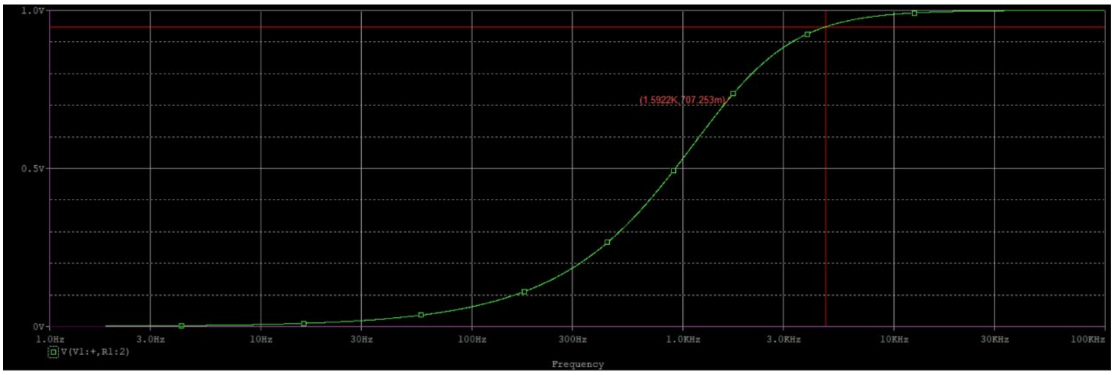


Fig. 10. Cut-off frequency of the output voltage

I change the frequency until the ordinate reaches 0.707V, the corresponding frequency is cut-off frequency. **The value of Cut-off frequency is 1.5922 kHz.** It is the same as the first question.

c)

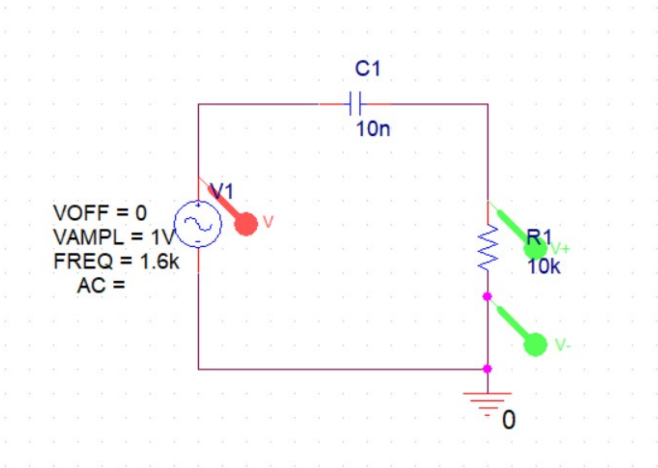


Fig. 11. Phase shift at 1.6 kHz

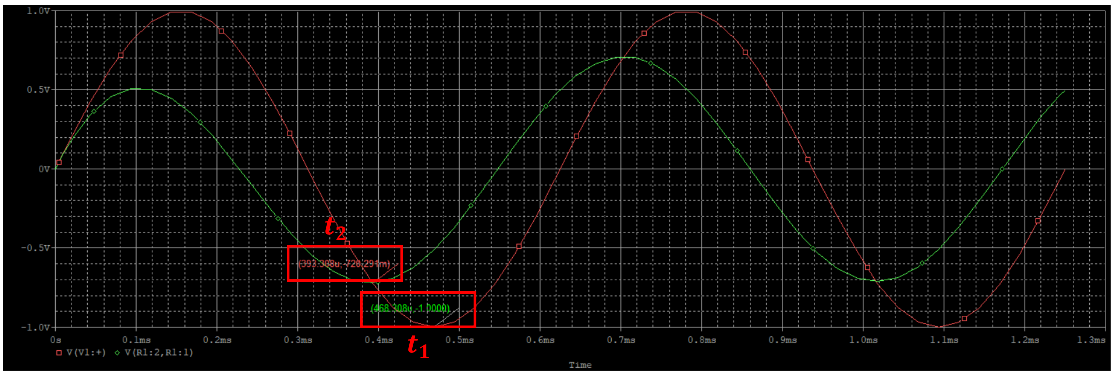


Fig. 12. The waveform of phase shift

The simulation is shown in figure 12. The red curve is input voltage, the green curve is output voltage. The time of wave trough corresponding to $\boldsymbol{V_{in}}$ **is:** $\boldsymbol{t_1 = 468.308\,\mu s}$, and the time of wave trough corresponding to V_{out} is $\boldsymbol{t_2 = 393.308\,\mu s}$. The frequency is also 1.6 kHz, so the period T=0.625 ms. To ensure more accurate results, I selected twice the period as the time domain. In addition, to avoid large error at the beginning of the simulation, I chose the wave through as the experiment data.

$$\frac{\boldsymbol{t_1 - t_2}}{\boldsymbol{T}} = \frac{\boldsymbol{\theta}}{\boldsymbol{2\pi}}$$

Thus, the phase shift $\boldsymbol{\theta = 0.754}$. From the figure 12, I can find that the phase of the output voltage is ahead of the input voltage. Therefore, the value of phase shift can be preliminary verified.

d)

According to theoretical calculation: when $X_c = R$, the corresponding frequency is cut-off frequency.

$$R = X_c = \frac{1}{2\pi f c}$$

$R = 10\,k\Omega, C = 10\,nF$.

$$f = \frac{1}{2\pi RC} = \boldsymbol{1.5915\,kHz}$$

In part b), the cut-off frequency is 1.5922 kHz. It is remarkably like the result calculated in this part d). Therefore, it can be proved that the cut-off frequency meets the scientific expectation.

Next, verify the part c). At 1.6 kHz, $f = 1.6\,kHz, C = 10\,nF$.

$$X_c = \frac{1}{2\pi f c} = 9.95 \times 10^3\,\Omega$$

This is high-pass filter, but the components are not changed. Therefore, the relationship between X_c and R is same as question 1.

$$\frac{V_0}{V_i} = \frac{R\angle 0^\circ}{R - jX_c}$$

$$= \frac{R\angle 0°}{\sqrt{R^2 + {X_c}^2}\angle - arctan\left(\frac{X_c}{R}\right)}$$

$$= \frac{R}{\sqrt{R^2 + {X_c}^2}}\angle arctan\left(\frac{X_c}{R}\right)$$

Therefore, the phase shift or the phase angle is $\boldsymbol{arctan\left(\frac{X_c}{R}\right)}$.

$$\boldsymbol{\theta = arctan\left(\frac{X_c}{R}\right) = 0.783}$$

$R = 10\ k\Omega, X_c = 9.95 \times 10^3\ \Omega$. Thus, the phase shift is 0.783. In the part c), the lab result is 0.754, it is remarkably like the theoretical results. Therefore, it can be proved that the phase shift meets the scientific expectation.

e)

This circuit can be used as high-pass filter. It can enable signals higher than the cut-off frequency to pass to a large extent, while signals lower than the cut-off frequency will prevent passing. High-pass filter can use in speakers for amplification. It can used in image processing for sharping the images. It can prevent amplification of DC current which can harm amplifiers. It can also be used for AC coupling and in various control systems, audio processing.

f)

Since this circuit is identical to the circuit components in question 3.1, the reasons for errors are the same. These 3 factors remain: *circuit tolerance, temperature, and reading errors*.

3.3. Simulate the Active bandpass filter

a)

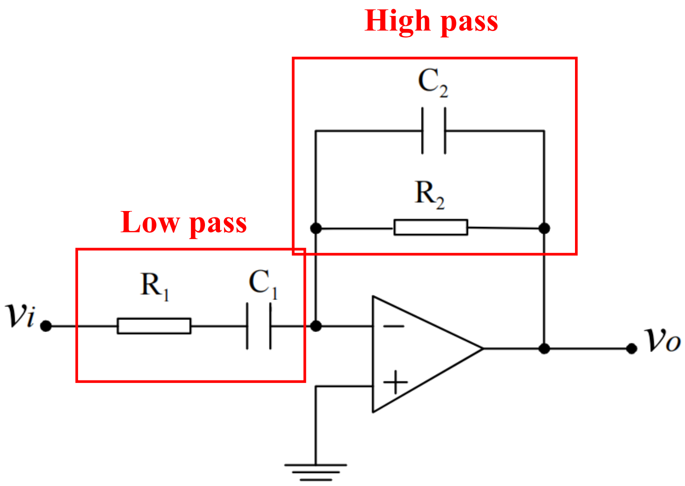


Fig. 13. Active bandpass filter

This is the active bandpass filter; the parallel part is a high pass filter, and the series part is a low pass filter. Thus, it can be regarded as a band-pass filter.

Let parallel part is Z_2, the series part is Z_1.

$$Z_1 = Z_{C_1} + R_1 = R_1 - jX_{C_1} = R_1 - j\frac{1}{\omega C_1}$$

$$Z_2 = \frac{Z_{C_2} \cdot Z_{R_2}}{Z_{C_2} + Z_{R_2}} = \frac{-j\frac{R_2}{\omega C_2}}{R_2 - j\frac{1}{\omega C_2}}$$

$$\frac{V_0}{V_i} = -\frac{Z_2}{Z_1} = -\frac{\frac{-j\frac{R_2}{\omega C_2}}{R_2 - j\frac{1}{\omega C_2}}}{R_1 - j\frac{1}{\omega C_1}} = \frac{\frac{jR_2}{R_2\omega C_2 - j}}{\frac{R_1\omega C_1 - j}{\omega C_1}} = \frac{jR_2\omega C_1}{(R_2\omega C_2 - j)(R_1\omega C_1 - j)}$$

$$= -\frac{j\omega R_2 C_1}{(1 + jR_2\omega C_2)(1 + jR_1\omega C_1)}$$

Let $K = R_2 C_1, \omega_1 = \frac{1}{R_1 C_1}, \omega_2 = \frac{1}{R_2 C_2}$. Thus, the formula can be reduced as

$$\boldsymbol{\frac{V_0}{V_i} = -\frac{Kj\omega}{(1 + \frac{j\omega}{\omega_1})(1 + \frac{j\omega}{\omega_2})} = -\frac{Kj2\pi f}{(1 + \frac{jf}{f_1})(1 + \frac{jf}{f_2})}}$$

The midband gain $A_0 = -\frac{R_2}{R_1}$.

The known quantity is $f_1 = 75\ Hz, f_2 = 31\ kHz,\ R_1 = 2.2\ k\Omega,\ and\ A_0 = -2.5$.

$$A_0 = -\frac{R_2}{R_1} = -2.5$$

Thus, the value of R_2 is

$$\boldsymbol{R_2 = 5.5\ k\Omega}$$

$$\omega_1 = 2\pi f_1 = \frac{1}{R_1 C_1}$$

$$\boldsymbol{C_1 = \frac{1}{2\pi R_1 f_1} = 9.64 \times 10^{-7}\ F = 964\ nF}$$

$$\omega_2 = 2\pi f_2 = \frac{1}{R_2 C_2}$$

$$\boldsymbol{C_2 = \frac{1}{2\pi R_2 f_2} = 0.934\ nF}$$

The bandwidth is $f_2 - f_1 = 30{,}925\ Hz$.

b)

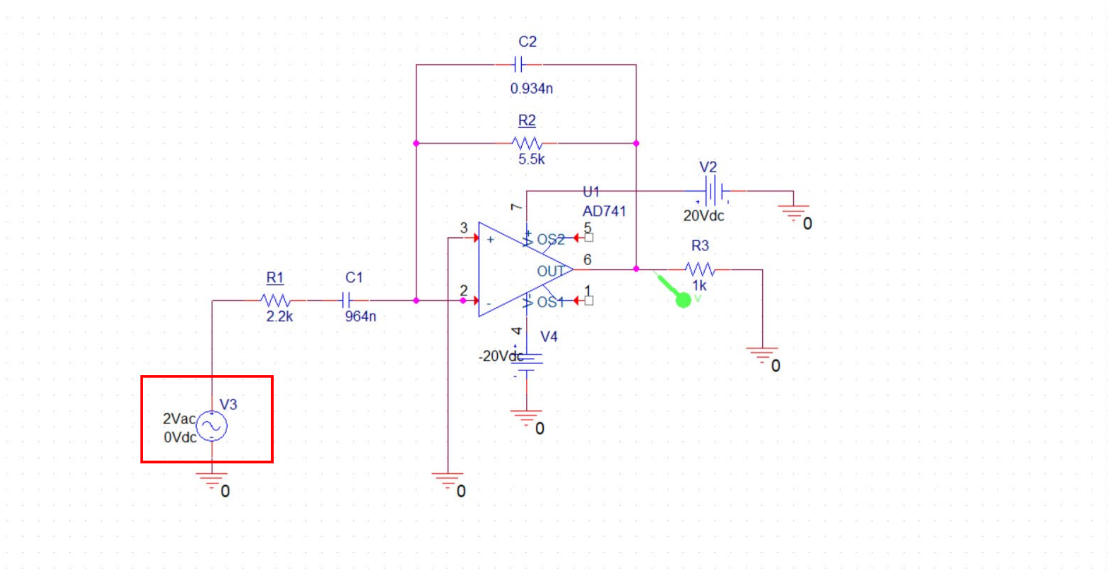


Fig. 14. Operational amplifier with AD741

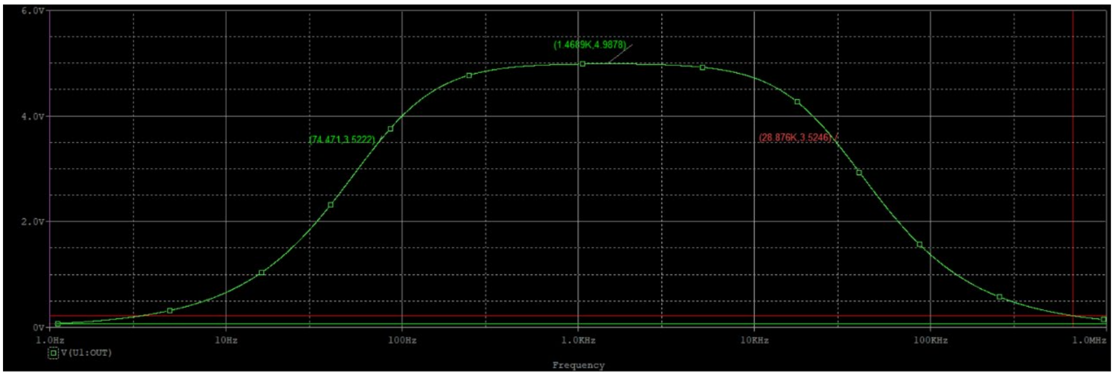


Fig. 15. Frequency response of Op-Amp of AD741

The frequency response of Op-Amp is shown in figure 15. From the figure, the maximum voltage is 4.9878V. Thus, the output voltage $\boldsymbol{V_{out} = 4.9878\,V}$. The value of input voltage is shown in figure 14, $\boldsymbol{V_{in} = 2V}$. Since the input voltage and output voltage are in opposite phases. Thus:

$$\boldsymbol{A_0 = -\frac{V_{out}}{V_{in}} = -\frac{4.9878}{2} = -2.4939}$$

The cut-off frequency (-3dB) is the frequency corresponding to 0.707 times of the output voltage. The lower cut-off frequency $\boldsymbol{f_1 = 74.471\ Hz}$, and the higher cut-off frequency $\boldsymbol{f_2 = 28.876\ kHz}$. Therefore, the bandwidth is $f_2 - f_2 = 28.783\ Khz$.

In addition, I made a simulation with the **controlled power supply.**

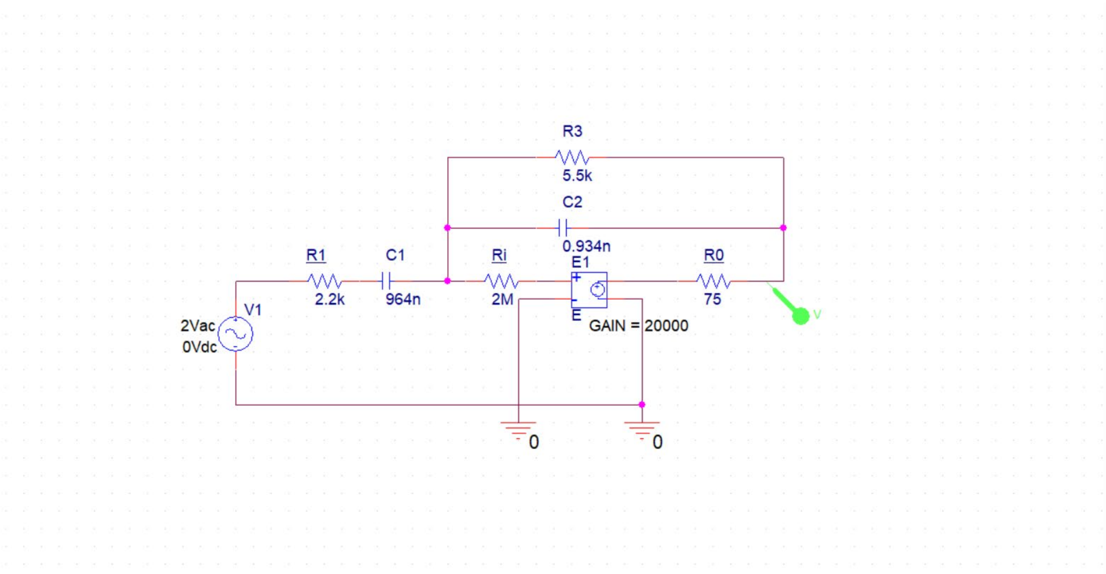


Fig. 16. Bandpass filter with VCVS

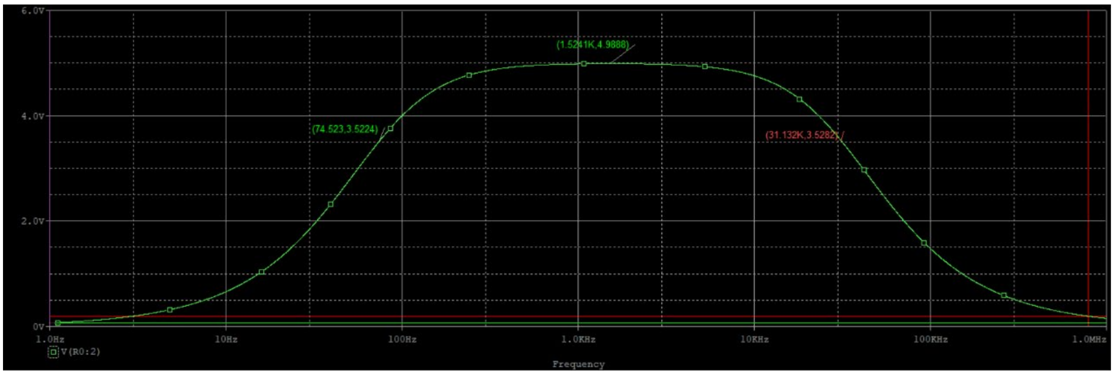


Fig. 17. Frequency response of VCVS

The output voltage is 4.9888V, and in 741 Op-Amp, the value of output voltage is 4.9878V. The simulation is very similar to the Op-Amp. It can be proved that VCVS and operational amplifier have the same effect. Thus, in the next question, I will use the Op-Amp to complete the following operations.

3.4. Design and simulation of active filter

a)

In this part, I took **four groups of data** to test the characteristics of the circuit. The range of resistance values I select should be 1kΩ to 100kΩ, the range of capacitors should be 1nF to 1μF.

(1) The 1st data

Firstly, I chose one resistor $\boldsymbol{R_1 = 1.5\ k\Omega}$ in TABLE Q4 to re verify the formula of the transfer function in step (a). Like the step (a), set $\boldsymbol{f_1 = 75\ Hz, f_2 = 31\ kHz, A_0 = -2.5}$.

$$A_0 = -\frac{R_2}{R_1} = -2.5$$

Thus, the value of R_2 is

$$\boldsymbol{R_2 = 3.75\ k\Omega}$$

$$\omega_1 = 2\pi f_1 = \frac{1}{R_1 C_1}$$

$$\boldsymbol{C_1 = \frac{1}{2\pi R_1 f_1} = 1.41\ \mu F}$$

$$\omega_2 = 2\pi f_2 = \frac{1}{R_2 C_2}$$

$$\boldsymbol{C_2 = \frac{1}{2\pi R_2 f_2} = 1.369\ nF}$$

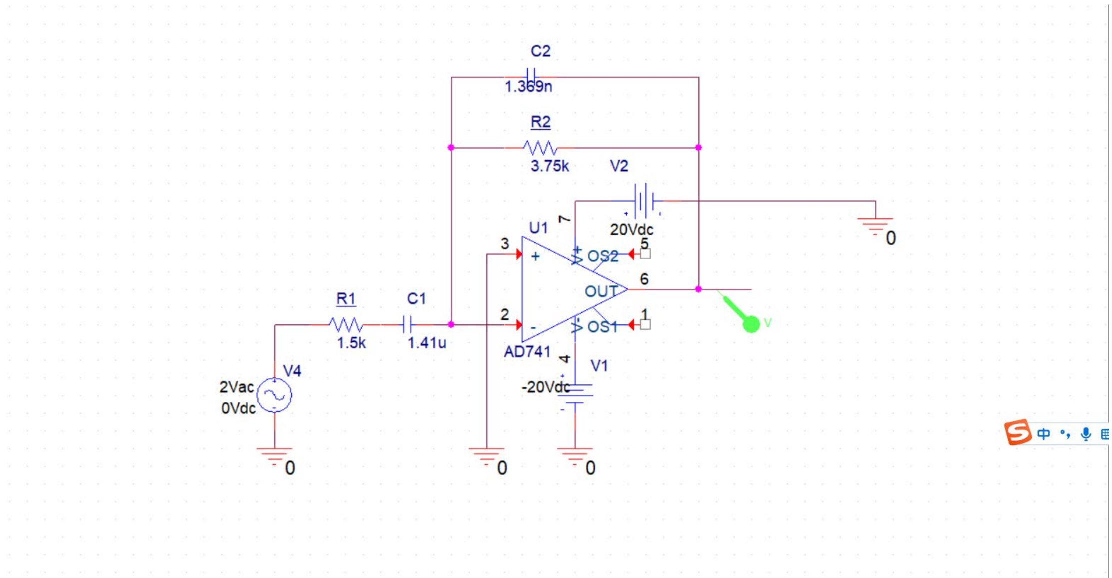


Fig. 18. Circuit diagram of 1st data

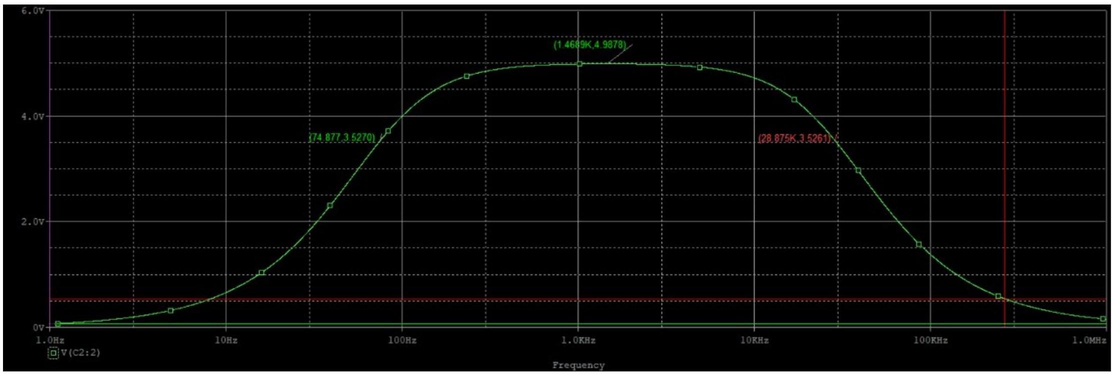


Fig. 19. Frequency response of 1st data

$V_{out} = 4.9978V,$ $\boldsymbol{f_1 = 74.877\ Hz, f_2 = 28.875\ kHz.}$

$$A_0 = -\frac{V_{out}}{V_{in}} = \mathbf{-2.499}$$

The experimental results agree with the theoretical results. Therefore, the formula in the step (a) can be proved again.

(2) The 2nd data

Secondly, I chose a group of values very close to the step (a). $R_1 = 2.2\ k\Omega, R_2 = 5.6\ k\Omega, C_1 = 1\mu F, C_2 = 1\ nF.$

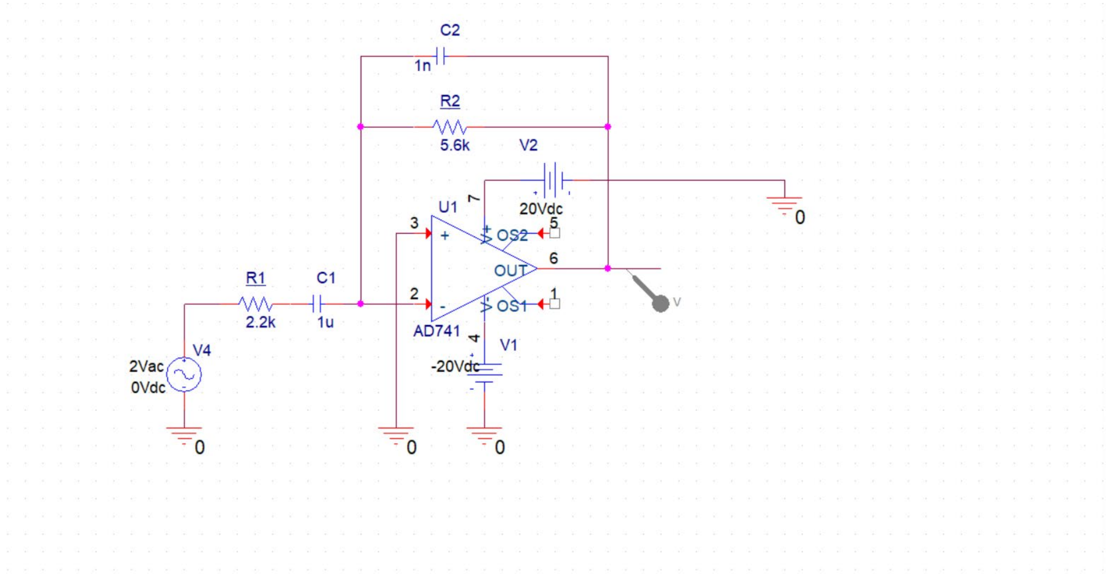


Fig. 20. Circuit diagram of 2nd data

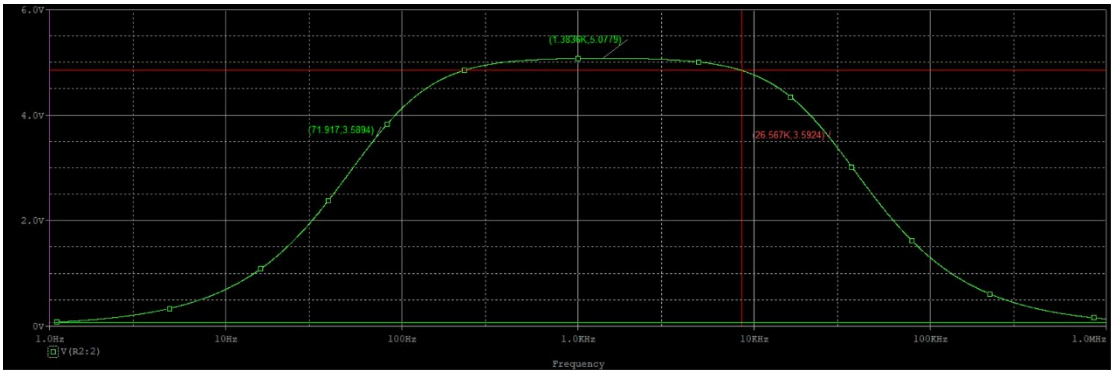


Fig. 21. Frequency response of 2nd data

In the bandwidth, the output voltage is 5.0779V, the lower cut-off frequency is 71.917 Hz, and the higher cut-off frequency is 26.567 kHz. The bandwidth is **26.495 kHz.** The midband gain is $\frac{V_0}{V_i} = \mathbf{2.539}$.

(3) The 3rd data

$R_1 = 2.2\ k\Omega, R_2 = 5.6\ k\Omega, C_1 = 0.33\mu F, C_2 = 4.7\ nF.$

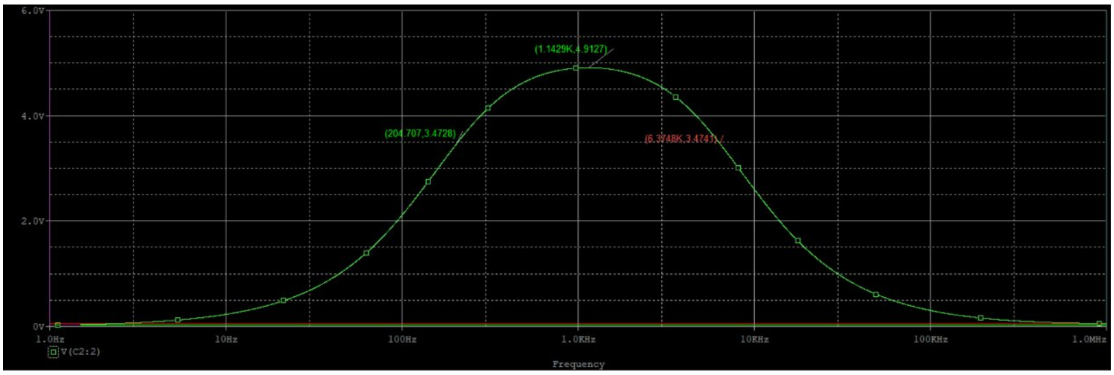


Fig. 22. Frequency response of 3rd data

In the bandwidth, the output voltage is 4.9127V, the lower cut-off frequency is 204.707 Hz, and the higher cut-off frequency is 6.3748 kHz. The bandwidth is **6.1701 kHz**. The midband gain is $\frac{V_0}{V_i} = \mathbf{2.456}$.

(4) The 4th data

$R_1 = 2.2\ k\Omega, R_2 = 5.6\ k\Omega, C_1 = 33\ nF, C_2 = 22\ nF.$

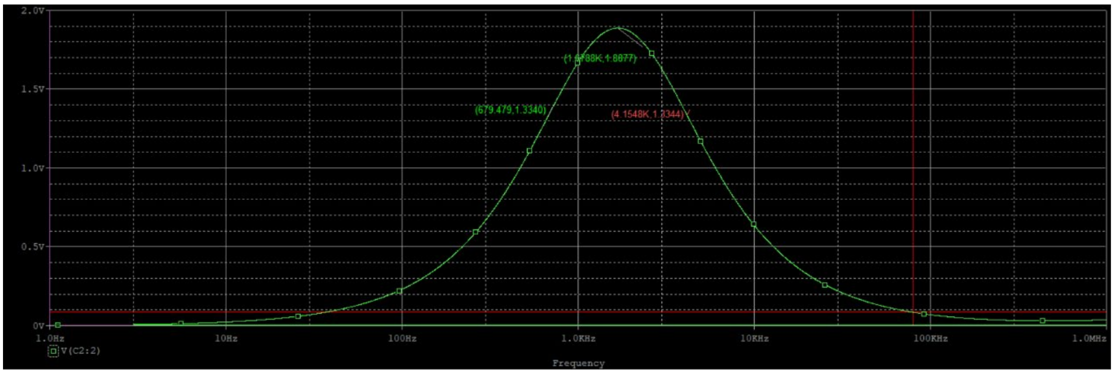


Fig. 23. Frequency response of 4th data

In the bandwidth, the output voltage is 1.8877V, the lower cut-off frequency is 679.479 Hz, and the higher cut-off frequency is 4.1548 kHz. The bandwidth is **3.475 kHz**. The midband gain is $\boldsymbol{\frac{V_0}{V_i} = 0.944.}$

● Result analysis:

(1) According to the rules found in the experiment

In the second, third and fourth group of data. I fixed the value of resistances R_1 *and* R_2, and change the value of capacitances C_1 *and* C_2. In (b), (c), (d) three groups of data, I gradually narrow the gap of the value of C_1 *and* C_2. I can find that the lower cut-off frequency is gradually increase and the higher cut-off frequency is gradually decrease. This leads to a gradually **decrease in bandwidth**. In addition, the value of output voltage is gradually decrease. Thus, **the midband gain is decrease**.

This is due to $f_1 = \frac{1}{2\pi R_1 C_1}, f_2 = \frac{1}{2\pi R_2 C_2}$, C_1 is decrease and $C_2$is increase, so $f_1$is increase and f_2 is decrease. From the figure 21, 22, and 23, the shape of the curve is getting sharper and sharper. We call the filter in Figure 21 a **broadband pass filter** and the filter in Figure 23 a **narrowband pass filter**.

The **general band-pass filter** is a broadband filter such as figure 21. It can filter the lower cut-off frequency f_L and the higher cut-off frequency f_H. It has two characteristic frequency points. For example, *audio amplifier*, only retain the frequency within 10Hz~50kHz.

Narrow band pass filter, as shown in figure 23. That is, only the signals in the narrow frequency bands on both sides of a certain center frequency f_c are allowed to pass through, and it has only one characteristic frequency. For example, some *frequency selective amplifiers* are realized by LC resonance. Resonance occurs only at a certain frequency point, resulting in large voltage gain. At the peripheral frequency, the gain decays rapidly.

(2) Second-order bandpass filter.

Figure 13 use second-order active bandpass filter. Compared with first-order filter, it has better filtering effect. Some complex filters can be written in the following more general transfer form.

$$A(S) = A_m \times \frac{1 + m_1 S + m_2 S^2 + \cdots + m_m S^m}{1 + n_1 S + n_2 S^2 + \cdots + n_n S^n}$$

Where $n \geq m$, n is called the order of the filter.

For instance, the second-order narrowband pass filter is:

$$A(S) = A_m \times \frac{\frac{S}{Q}}{1 + \frac{S}{Q} + S^2}$$

The higher the order of the filter, the more complex its transfer function expression and the corresponding circuit are. However, its filtering effect is also closer to the ideal **brick wall filter**. A brick wall filter is a straight line that is not 0 or 1. Like a brick wall, there is only one wall and there is no full opening.

As shown in figure 24. Green is the ideal **brick wall - low pass**, blue is the amplitude frequency characteristic of the **first-order low-pass filter**, and red is the amplitude frequency characteristic of **a second-order filter**. Obviously, the second-order filter is closer to the brick wall.

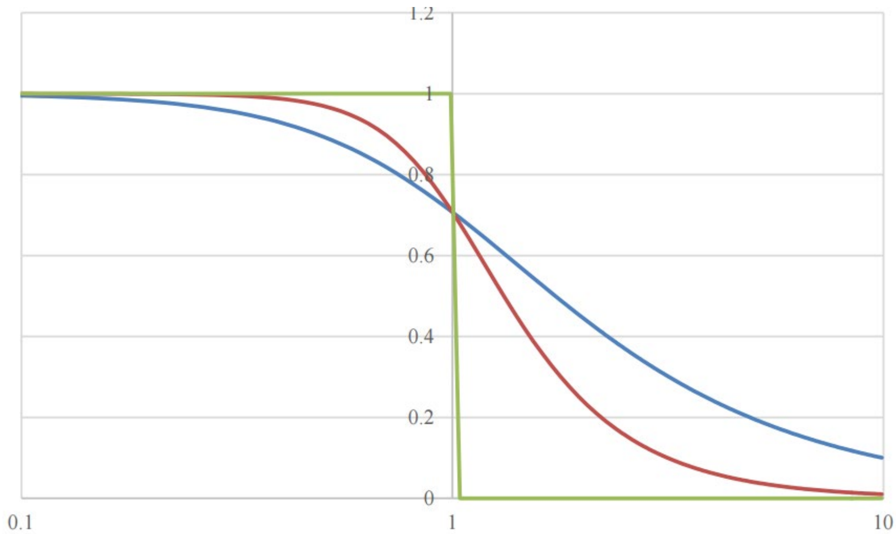


Fig. 24. First order low-pass, second order low-pass and brick wall low-pass

b) The technical merits and drawbacks of the passive and active filters

The merits of passive filter:

1) At high voltage and current, many active devices will fail, while passive devices are generally unrestricted.

2) At ultra-high frequencies, passive devices have inherent advantages.

As shown in figure 25, the open loop gains of the operational amplifier changes with the frequency, and generally decreases with the increase of the frequency.

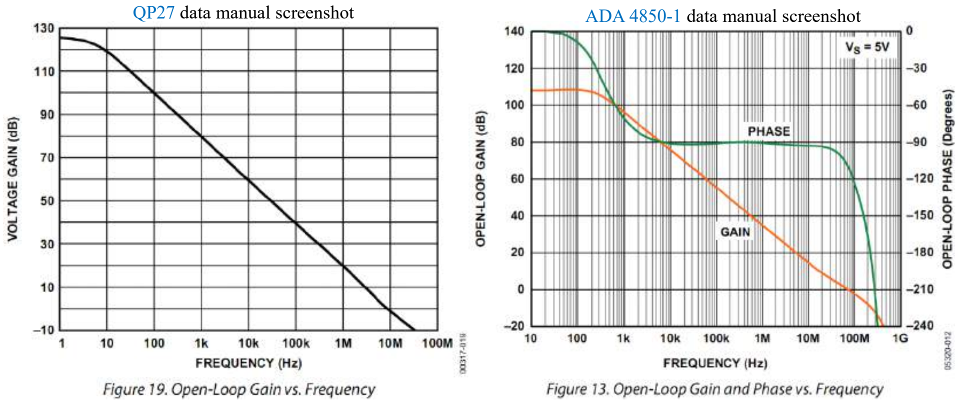


Fig. 25. Open loop gain curve of actual operational amplifier

In the closed-loop gain, the phenomenon that the gain changes with frequency becomes less obvious. Figure 26 shows the frequency response of two open-loop gains and two close-loop gains.

A_{umo1} *and* A_{umo2} are two open-loop gains curve, A_{ufm1} *and* A_{ufm2} are two close-loop gains curve. The open loop gain of the two Op-Amps decreases continuously with the increase of frequency. However, the closed-loop gain formed by them is always 10 and always coincides. This fact persisted until about 10^5Hz=100 kHz. It began to decline. At 1MHz, it can already see a significant decline.

The **bandwidth** of the closed loop is very large, which is why the closed loop amplifier circuit can be used as a filter.

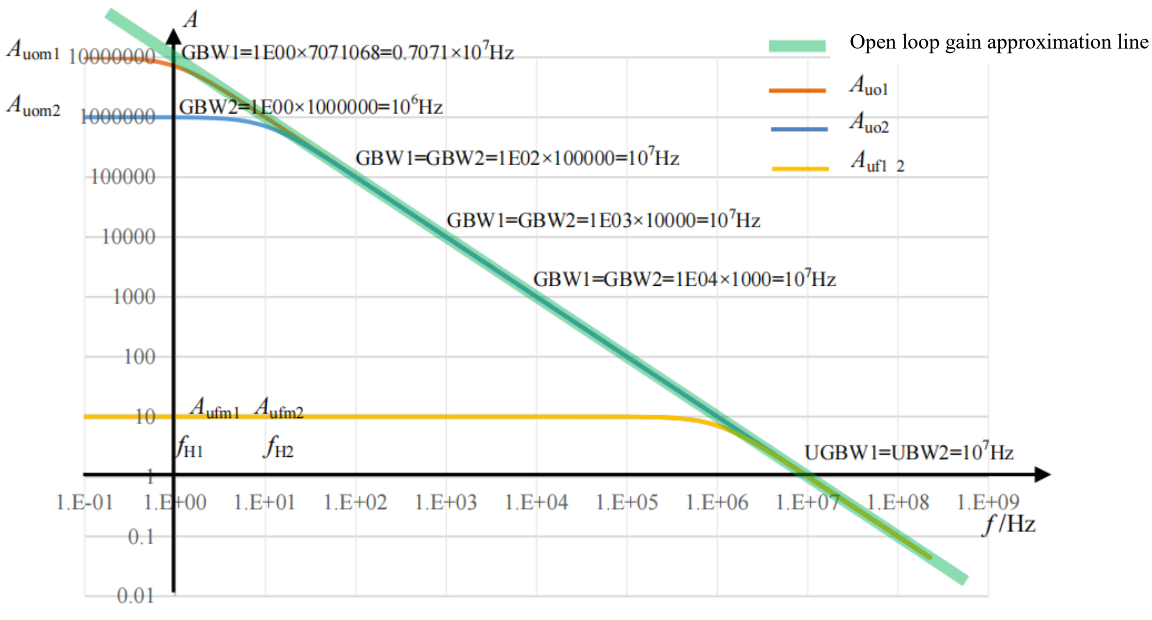


Fig. 26. Open loop and closed loop gain

However, in the **ultra-high frequencies**, the close-loop gain will also still decrease. The passive filter has no such problem.

3) Passive circuits have an advantage when implementing the simplest filtering.

4) Passive components are cheaper than active components, unless large inductors and capacitors are used.

- ### The merits of active filter:

1) Negative feedback and amplification can be introduced. Therefore, extremely complex filters can be realized, and small signals can be easily handled.
2) The **cascade** of multistage filters can be easily realized. However, the interaction between the levels of passive filters is extremely complex, and multistage cascade is very difficult.
3) For **ultra-low frequencies**, active filters have natural advantages. It can use feedback network and Miller equivalent method to replace super large capacitance and inductance with small capacitance. The lower the characteristic frequency is, the greater the capacitance value is required. Even if there is a super capacitor now, it requires a large enough area and a small enough space to make a capacitor, which is physically limited. The only way to achieve ultra-low frequency filters with passive circuits is to use super large capacitors, which is very difficult.
4) The circuit calculation is relatively simple.

4. Conclusion

This study set out to demonstrate our understanding of circuit analysis. To investigate the passive RC low-pass and high-pass filters, and active bandpass filter. In this study, I solved some basic problems of circuit analysis and verified the correctness of the theory through simulation. This study contributes to our understanding of passive RC low-pass and high-pass filters, find out the characteristics of active bandpass filter. These experiments confirmed that in active filter, different value of resistances and capacitors have a significant impact on bandwidth and gain. The research has also shown that broadband and narrow bandwidth filters have two distinct applications, narrow bandwidth filters have important applications in frequency selection.

A limitation of this study is that only one of the characteristics of the second-order active filter is studied, and no more values of resistance and capacitance are attempted. In addition, stop-band filter, notch filter and all pass filters are not studied.

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