Report on Pre-Lab 2

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3.1
After going over the op-amp's specifications, we find the typical values of the following parameters:
1.The most frequently used power supplies are ±15V,±12V,±10V and ±5V.
2.The typical value of input resistance is 2.5MΩ.
3.The typical value of output resistance is 100-20kΩ.
4.The typical value of open loop voltage gain is 20k-200k.
5.The typical value of slew rate is 0.5V/μs.

3.2.1
Because the op-amp is ideal, according to reference 5.3, it has virtual ground and virtual short circuit characteristics. Then we use its virtual short circuit characteristic to analyze the problem.

Because the two input ports of the amplifier have the same voltage, we find that

$$V_+ = V_-$$

And obviously,

$$V_+ = V_{in}$$

$$V_- = V_{out}$$

then we can derive that

$$V_{in} = V_{out}$$

So,

$$\frac{V_{out}}{V_{in}} = 1$$

3.2.2
Substitute slew rate to typical value in datasheet, we find that

$$t = \frac{V_t - V_0}{slewrate} = \frac{10V - (-10V)}{0.5V/\mu s} = 40\mu s$$

Referring to the large signal response to in the datasheet, the time we calculated is the same as the theoretical one.

3.2.3
As the solution in problem1, we know that

$$V_{out} = V_{in} = Acos(\omega t + \Phi)$$

So, the differentiation expression of v_{out} is

$$|\frac{dV_{out}}{dt}| = A\omega|sin(\omega t + \Phi)|$$

Obviously, the maximum value of v_{out} is

$$|\frac{dV_{out}}{dt}|_{max} = A\omega, when$$

$$\omega t + \Phi = k\pi + \frac{\pi}{2}, k = 0, 1, 2, 3...$$

As the definition of slew rate says,

$$slewrate = |\frac{dV_{out}}{dt}|_{max}$$

so,

$$slewrate = A\omega$$

If the amplitude is given, according to the expression above, we find that

$$\omega_{max} = \frac{slewrate}{A}$$

because $\omega = 2\pi f$
the maximum frequency is

$$f_{max} = \frac{slewrate}{2\pi A}$$

If the frequency is given, similarly we can easily find that

$$A_{max} = \frac{slewrate}{2\pi f_0}$$

3.2.4 From the expression of $|\frac{dV_{out}}{dt}|$ in previous problem, we can know the maximum value of $|\frac{dV_{out}}{dt}|$ is: Aω
Therefore, the slew rate(SR) = Aω

$$A = \frac{SR}{\omega} = \frac{SR}{2\pi f}$$

Then, if we let f=20Hz, A=$\frac{SR}{2\pi f}$ = $\frac{500000}{2\pi\times 20}$=3978.9V
Also,if we let f=20kHz, A=$\frac{SR}{2\pi f}$ = $\frac{500000}{2\pi\times 2\times 10^4}$=3.979V
Therefore, the value of A should be less than min3978.9, 3.979 = 3.979V
From the hint, we can know that A is usually in the range of [0.3, 2], which will obviously avoid slew rate limitation.

3.2.5

According to the question, because the input resistance is very large, the input current of op-amp is 0, while $V_{in+} \neq V_{in-}$ because of the finite open-loop gain A_v.

Therefore, from Figure 3.1 in the prelab document and the circuit model for op-amp, we can obtain the following expressions:

- $V_{out} = V_-$
- $V_+ = V_{in}$
- $V_{out} = AV_d$
- $V_d = V_+ - V_-$

Hence, the equation for the circuit gain V_{out}/V_{in} as a function of A_v is

$$\frac{V_{out}}{V_{in}} = \frac{A_v}{1 + A_v}$$

Obviously, if A_v=1, $\frac{V_{out}}{V_{in}}$ =0.5.

3.2.6

In item 5 we derive that

$$\frac{V_{out}}{V_{in}} = \frac{A_v}{1 + A_v} = 0.5$$

and the solution of the op-amp gain is

$$A_v = 1$$

Then we change the gain into decibel scale, which is

$$A_v(dB) = 20log|A_v| = 0dB$$

Then, we read the diagram on Canvas to find the frequency where the gain equals to 0dB.
As the diagram says,
for LM148 chips, the corresponding frequency is

$$f_{A_v=1} = 0.63MHz$$

For LM149 chips, the corresponding frequency is

$$f_{A_v=1} = 4.47MHz$$

In our Lab session, we use LM348 chips, whose characteristics are different from the two mentioned above. So, the comparison between this problem and 3.4 item 2 is meaningless.

As the instructions say, the frequency of audio signal is always between 20Hz and 20kHz. To spot them quickly, we calculate their value in log scale.

$$log_{10}20 = 1.30$$

$$log_{10}20000 = 4.30$$

For LM148 chips, the corresponding gains in decibel are

$$f = 20Hz, A_v(dB) = 90dB$$

and

$$f = 20000Hz, A_v(dB) = 30dB$$

Then the range of the op-amp gain is

$$31.6 \leq A_v \leq 3.16 \times 10^4$$

Finally, the range of $\frac{V_{out}}{V_{in}}$ is

$$0.96935 \leq \frac{V_{out}}{V_{in}} \leq 0.99997$$

For LM149 chips, the corresponding gains in decibel are

$$f = 20Hz, A_v(dB) = 108dB$$

and

$$f = 20000Hz, A_v(dB) = 46dB$$

Then the range of the op-amp gain is

$$199.53 \leq A_v \leq 2.51 \times 10^5$$

Finally, the range of $\frac{V_{out}}{V_{in}}$ is

$$0.995013 \leq \frac{V_{out}}{V_{in}} \leq 0.999996$$

From the results above, we figure out that when frequency significantly changes, the gain of the voltage follower is almost constant. This verifies the characteristic of the circuit, which serves as a buffer, block external noise and keeps the value of input voltage unchanged.

3.3.1

In frequency domain, the inpedance of a capacitor and a resistance are

$$Z_c = \frac{1}{j\omega C}, \quad Z_R = R$$

In this circuit, we can see

$$\begin{aligned} V_{out} &= (-Z_c//Z_R)(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}) \\ &= \frac{-R}{1 + j\omega RC}(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}) \end{aligned}$$

3.3.2

$$V_{out}(t) = -\frac{1}{C}\int_{t_0}^{t}(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3})dt + V_{out}(t_0)$$

3.3.3

In frequency domain, as $V_1, V_2, V_3, R_1, R_2, R_3$ are regular value, the value of V_{out} depends on

$$|V_{out}| \propto |\frac{R}{1 + j\omega RC}| = \frac{R}{\sqrt{1 + (\omega RC)^2}}$$

when $\omega = 0$. V_{out} gets its maximum value : $|R|$

For 70% of the output voltage, which means

$$\sqrt{(\omega RC)^2 + 1} = \frac{1}{0.7} \iff \omega = \frac{1}{RC}$$

For 50%, 30%, 10% of the output voltage.

$$\omega_1 = \frac{\sqrt{3}}{RC}, \omega_2 = \frac{\sqrt{10}}{RC}, \omega_3 = \frac{3\sqrt{11}}{RC}$$

3.3.4

$$\begin{aligned} V_1 &= 1\angle 0^\circ \\ V_2 &= 0.1\angle{-30^\circ} \\ V_3 &= 0.1\angle 30^\circ \end{aligned}$$

3.3.5

According to the circuit diagram we can get the following equation:

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = \frac{-V_{out}}{R_f//\frac{1}{j\omega C}}, \quad \omega = 2\pi f$$

Bring in known data, we can get

$$|V_{out}| = \frac{1.173}{\sqrt{1 + (1.382 \times 10^{-5} f)^2}}$$

$$|\varphi| = atan(-1.382 \times 10^{-5} \times f)$$

Figure 1shows the magnitude of the output signal in terms of frequency.

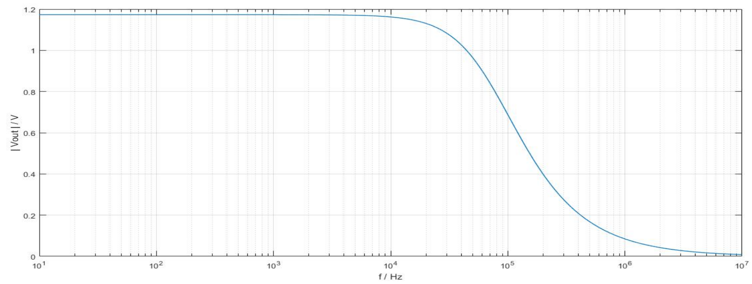

Figure 1: The magnitude of the output signal in terms of frequency

Figure 2shows the phase of the output signal in terms of frequency.

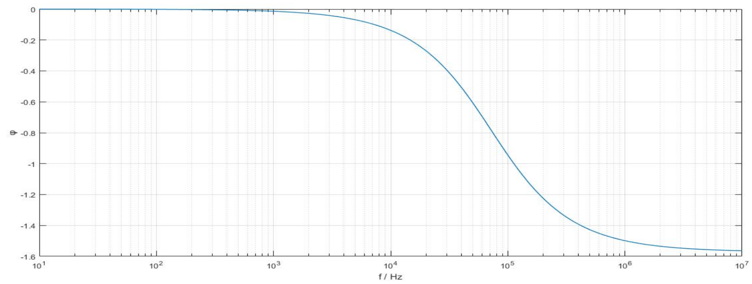

Figure 2: The phase of the output signal in terms of frequency

3.3.6

If the capacitor is removed, the magnitude of output voltage won't depend on frequency.

$$|V_{out}| = 1.1732V$$

The capacitor can play a role of filtering here, which can shield the high-frequency signal component in the input signal. Then, slew-rate limitation and non-ideal effects of the op-amp will be negligible. The experimental results are also more accurate.

3.4.1

We used MultiSim transient analysis to simulate this circuit in the time domain using a square wave input with an amplitude going from −10 V to +10 V, a frequency of 3 kHz, and a duty cycle of 50%.The input and output waveforms are shown as follows:

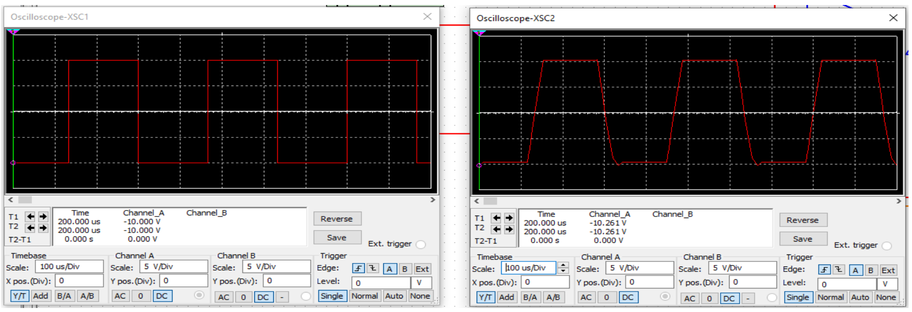

Figure 3: The waveforms of input and output

Then we measured the time interval for the output to reach the steady state after an input transition.

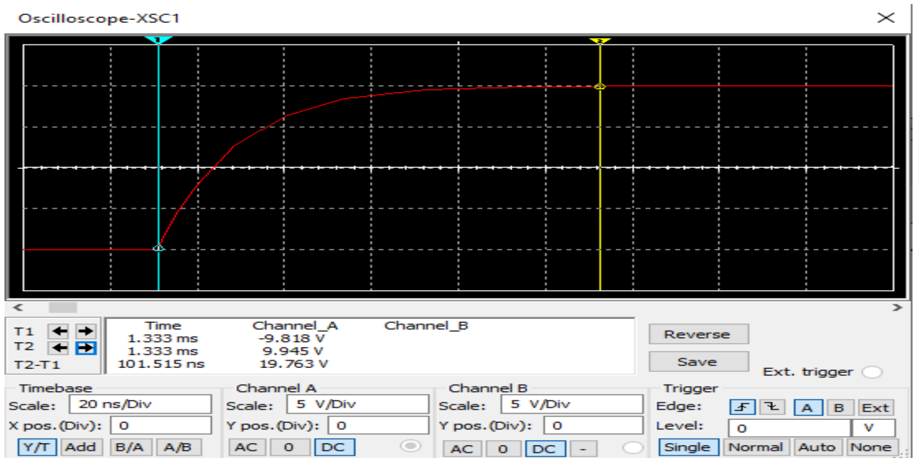

Figure 4: Measurement of the time interval

We can obtain:
Time interval is 101.515 ns.
Slew rate $= \frac{19.763}{101.515*10^{-9}} = 1.95 * 10^8 V/s$
3.4.2
We set the input signal to a sine wave with an amplitude of 100 mV (−100 mV to +100 mV peak-to-peak) and a frequency of 10 Hz.Then, we got the waveform of output signal:

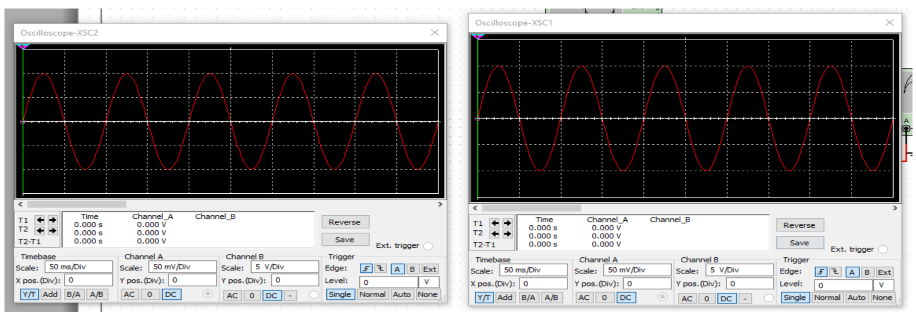

Figure 5: The waveforms of input and output signals

In order to find the frequency at which the voltage gain decreases to half of its maximum value, we used the AC analysis function in the MultiSim program.

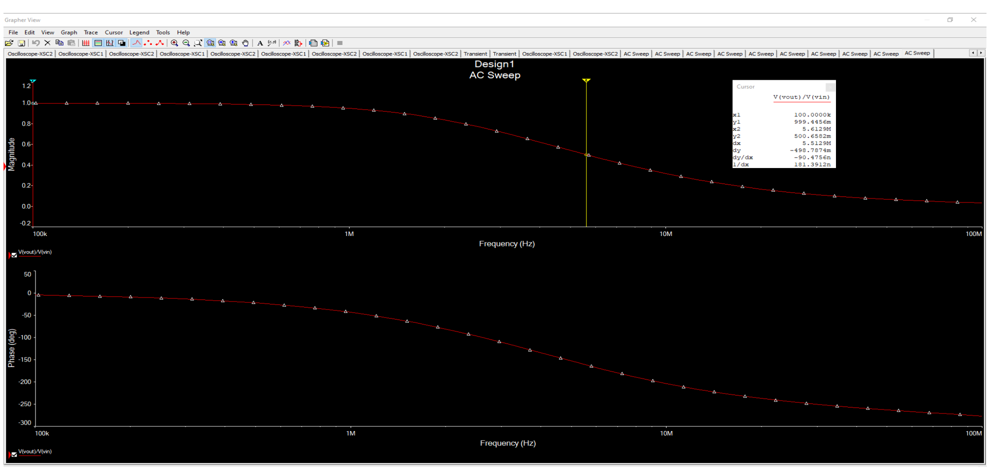

Figure 6: The waveforms of input and output signals

From the simulation results we can know, the frequency at which the voltage gain decreases to half of its maximum value is 5.6129MHz

3.4.3

For the circuit in Figure 3.2, we used MultiSim AC analysis to plot the output voltage from 10 Hz to 1 MHz. Figure7 shows the magnitude of the output signal in terms of frequency.

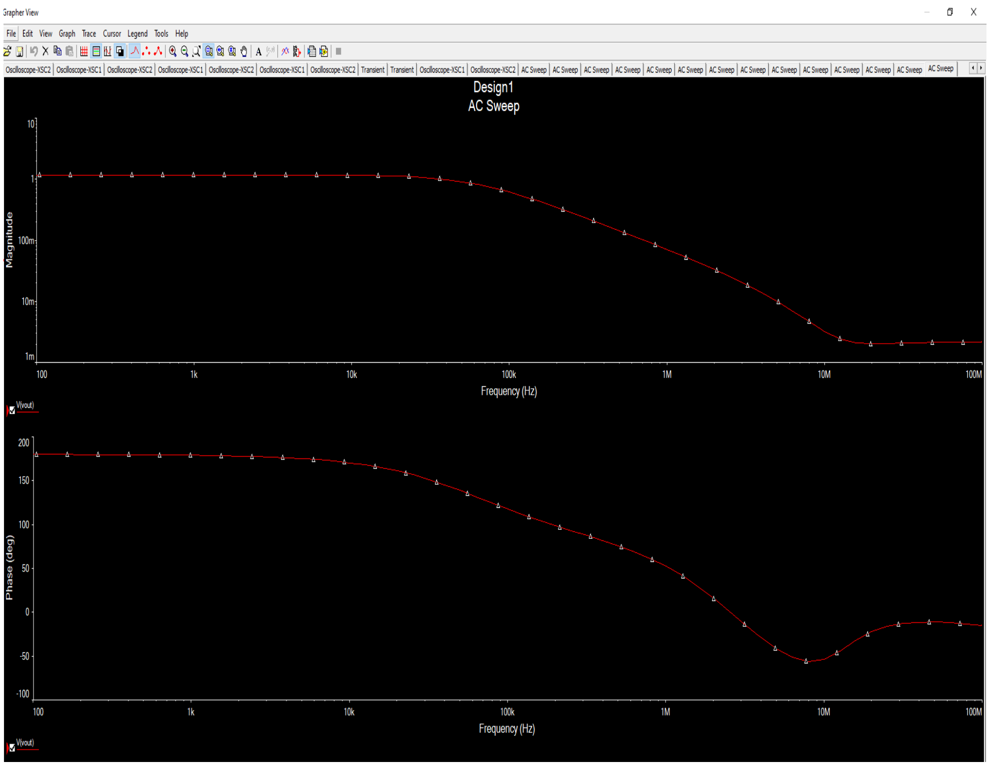

Figure 7: The magnitude of the output signal in terms of frequency

Figure 8 shows both magnitude and phase of the output signal in terms of frequency

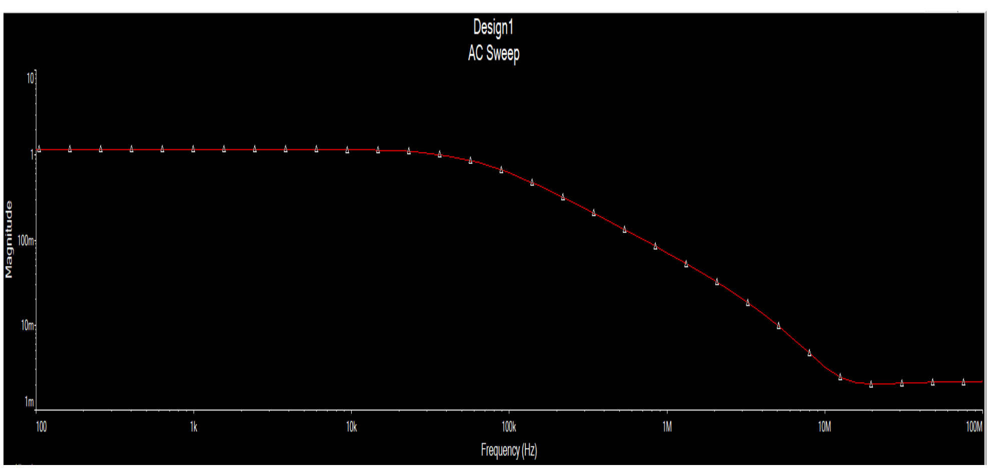

Figure 8: The magnitude and phase of the output signal in terms of frequency

Compared with the results of 3.3.5, the simulation results are consistent with the theoretical results.