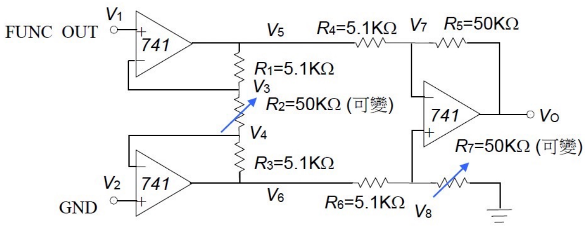
Lab 4 Differential Amplifier

1. Differential amplifier circuit diagram

Spec: gain should be at least 40 dB = 100 V/V



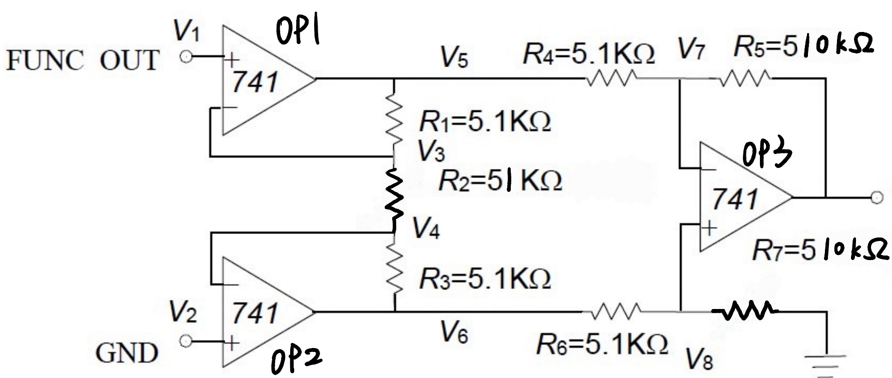
To simplify the problem, make $R_7 = R_5 \Rightarrow$

Total gain of instrumentation amplifier is $\left(\frac{R_1+R_2+R_3}{R_2}\right) \cdot \left(\frac{R_5}{R_4}\right)$

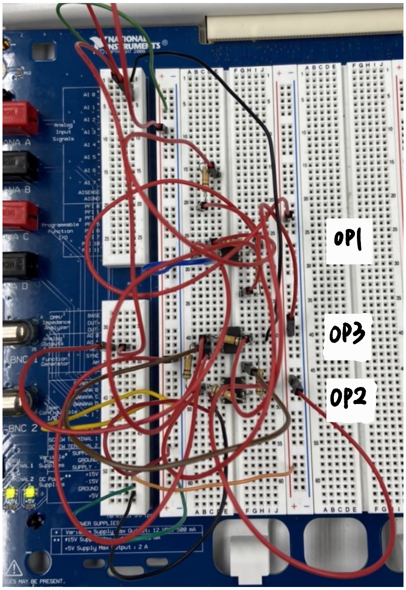
WLOG set $R_2 = 51\,k\Omega$, $R_5 = R_7 = 510\,k\Omega$ to meet the specification.

$$\text{Thus, the total gain} = \left(\frac{5.1k+51k+5.1k}{51k}\right) \cdot \left(\frac{510k}{5.1k}\right)$$

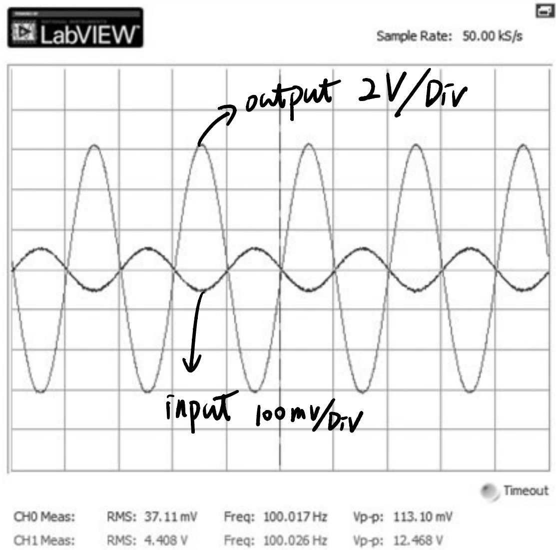
$$= 1.2 \cdot 100 = 120\,(V/V)$$



Physical circuit:

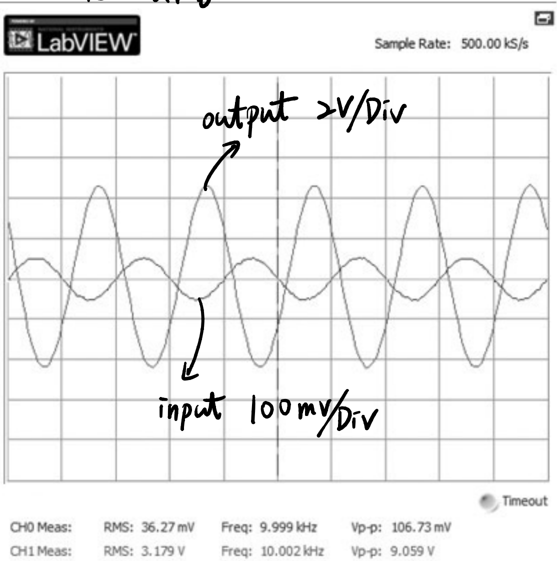


Input 100 Hz, 0.1 Vpp, $A_{100Hz} = \frac{12.468}{0.113} = 110\ V/V$



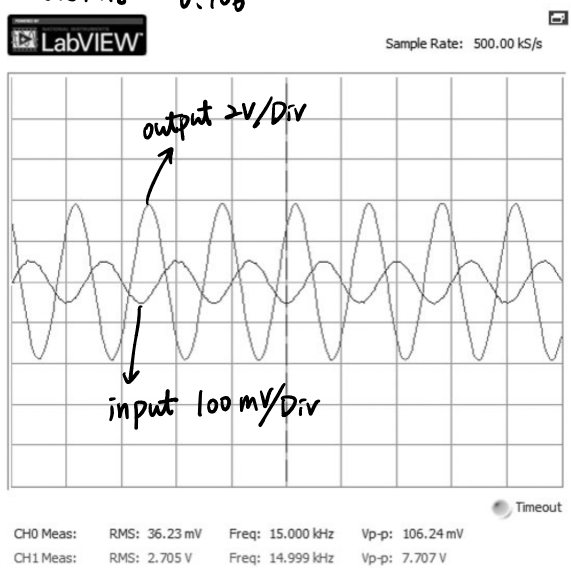
input 10000 Hz, 0.1 Vp.p.

$A_{10kHz} = \frac{9.059}{0.106} = 85.46\ (V/V)$



input 15000 Hz, 0.1 Vpp

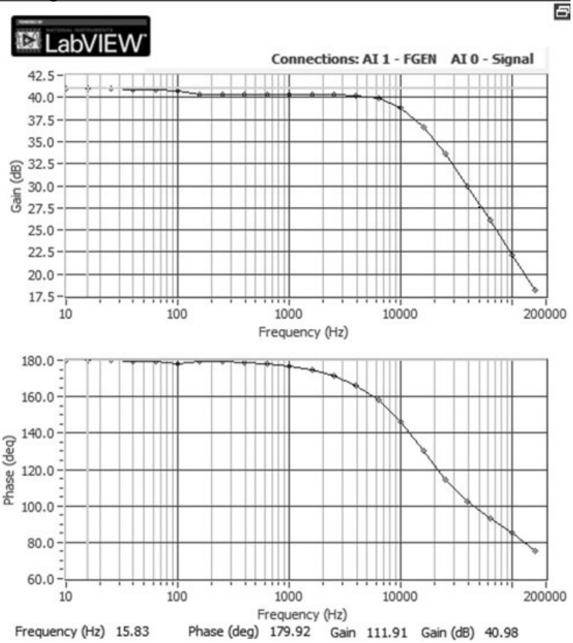
$A_{15kHz} = \frac{7.707}{0.106} = 72.69\ (V/V)$

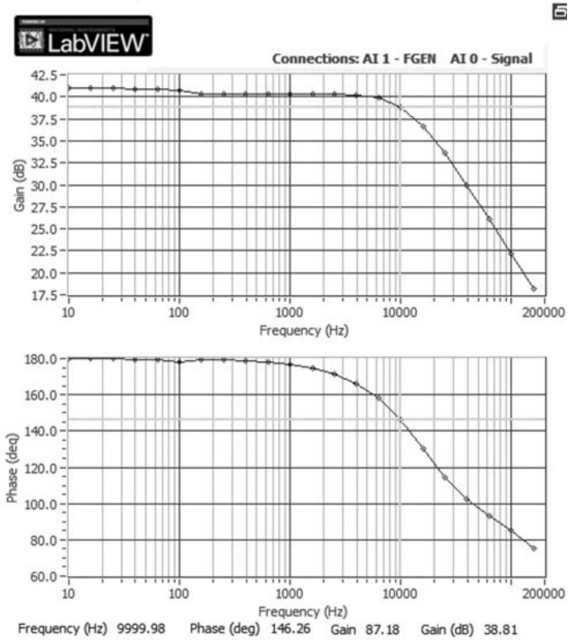


Physical circuit bode plot

Max gain $\approx 41\,dB = 10^{\frac{41}{20}} \approx 112.2\,(\frac{V}{V})$

-3dB point at 38dB with $f_0 \approx 10kHz$





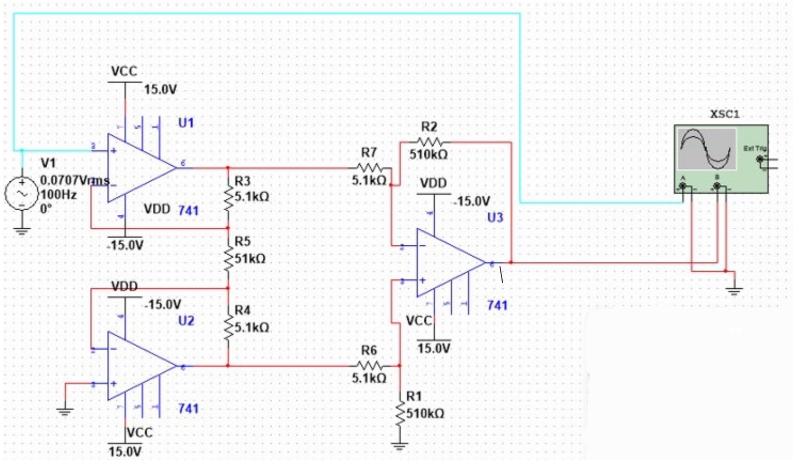
* Compare to three frequencies result

f	Gain (V/V)	Bode Plot Gain
100Hz	110	$41\,dB \approx 112\,(\frac{V}{V})$
10kHz	85	$38\,dB \approx 80\,(\frac{V}{V})$
15kHz	72	$36\,dB \approx 63\,(\frac{V}{V})$

It's obviously that 3 frequency results match bode plot.

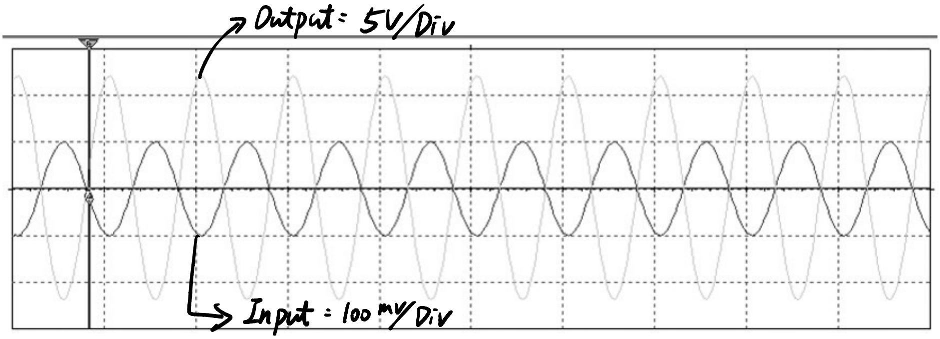
Differential Mode Multisim Simulation

Schematic:



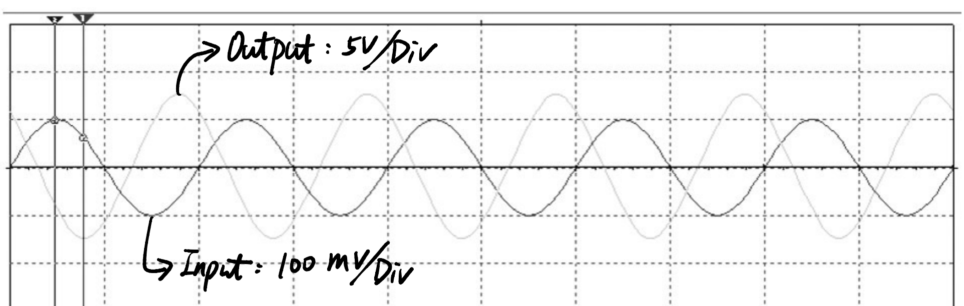
Input 100 Hz

$A_{100Hz} \approx 120 V/V$



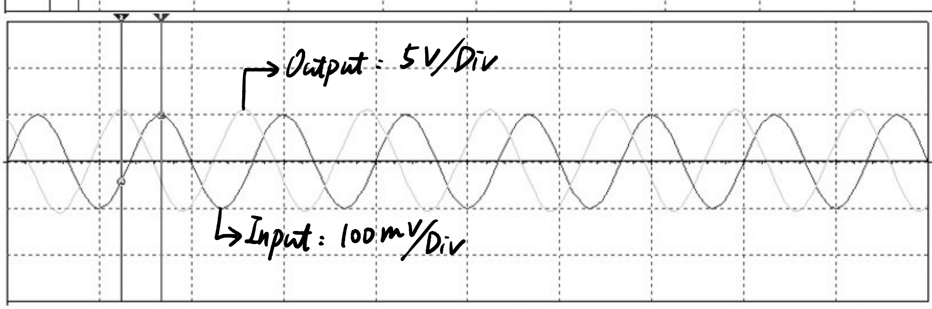
Input 10kHz

$A_{10kHz} \approx 80 V/V$



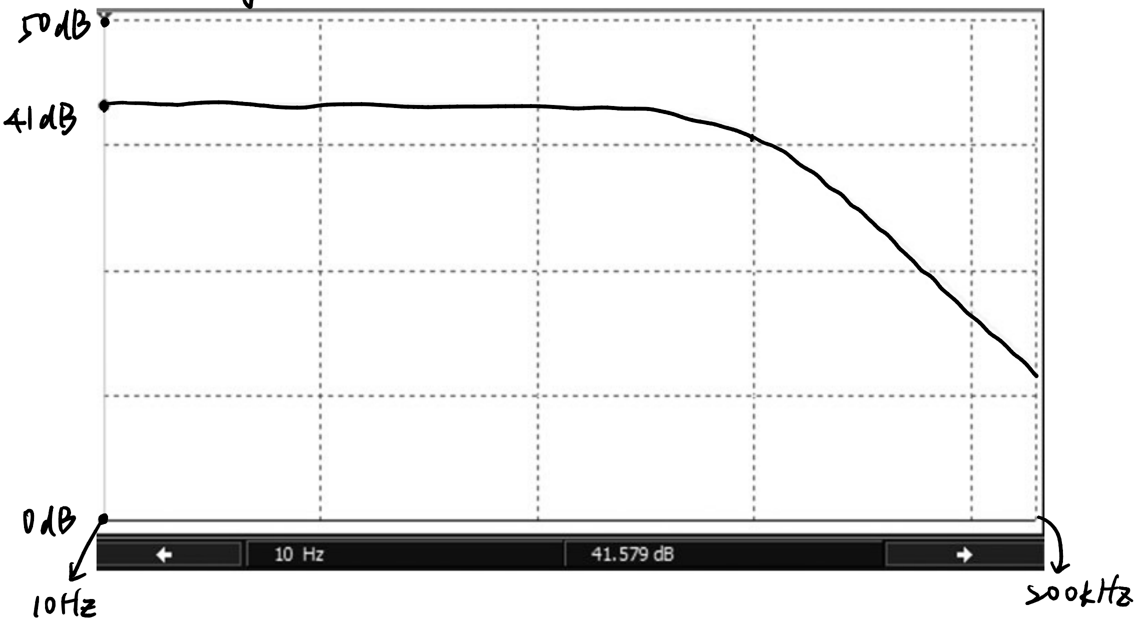
Input 15kHz

$A_{15kHz} \approx 60 V/V$

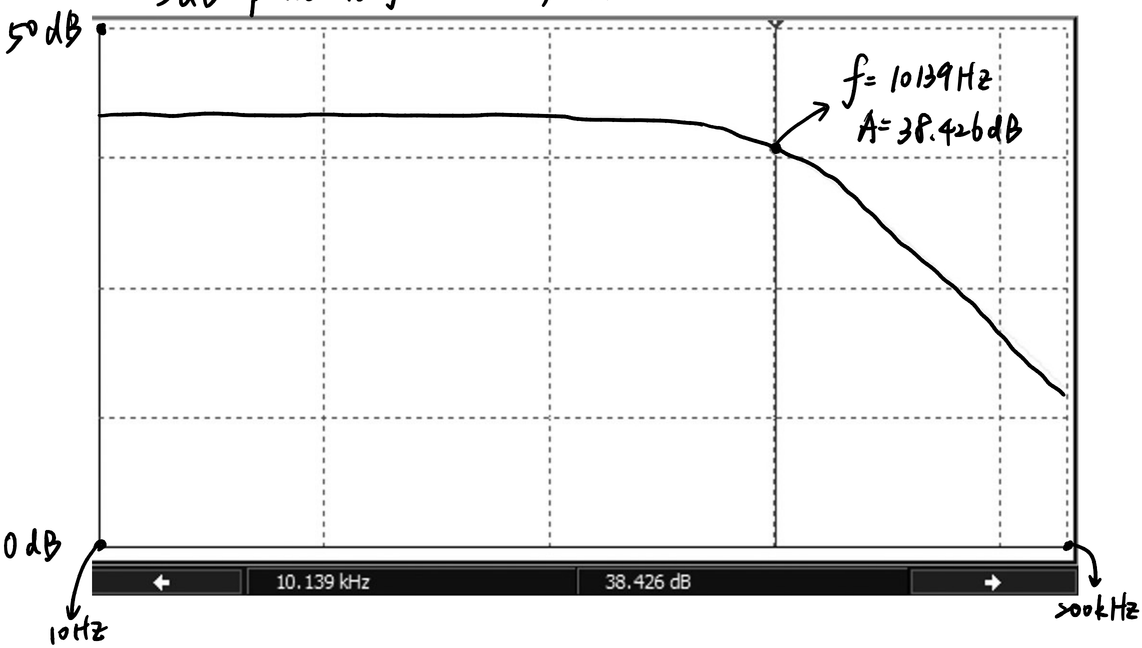


Bode Plot – Magnitude Response

Peak gain at $f = 10\,Hz$, $A = 41.579\,dB \approx 119.9\ V/V$

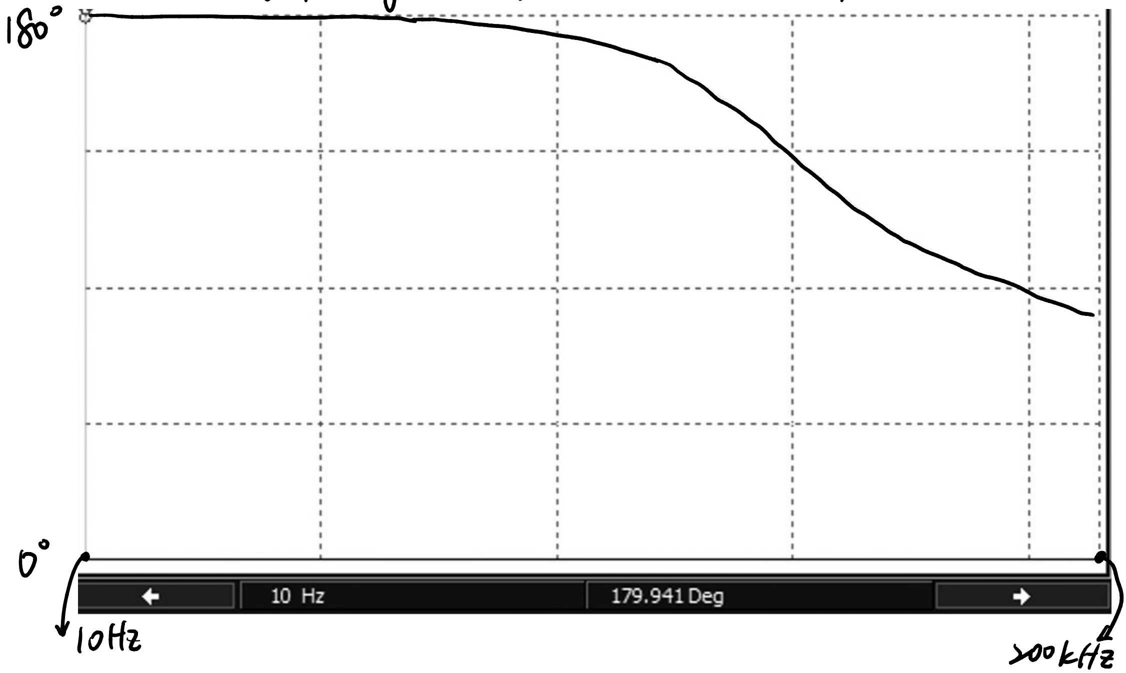


$-3\,dB$ point at $f \approx 10000\,Hz$, $A = 38.426\,dB \approx 83.42\ V/V$

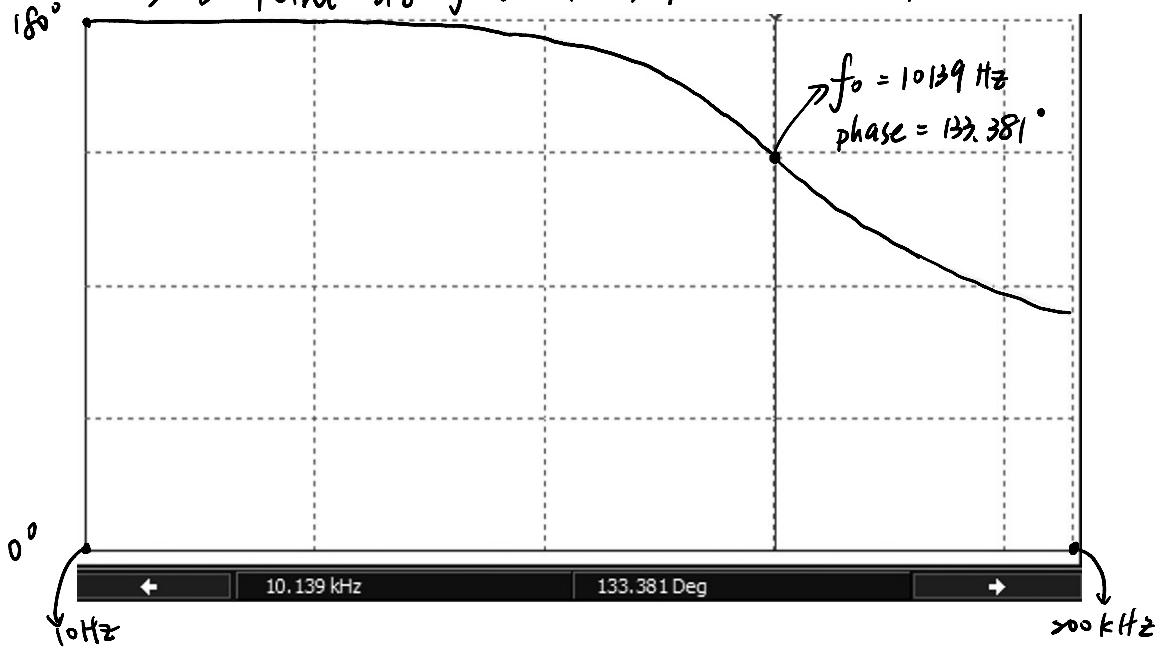


Bode Plot - Phase Response

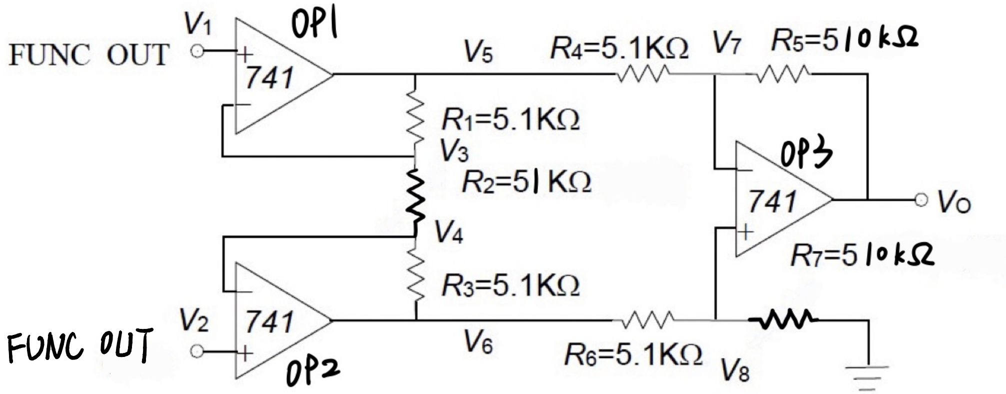
Phase at peak gain (10Hz) is 180° (out of phase)



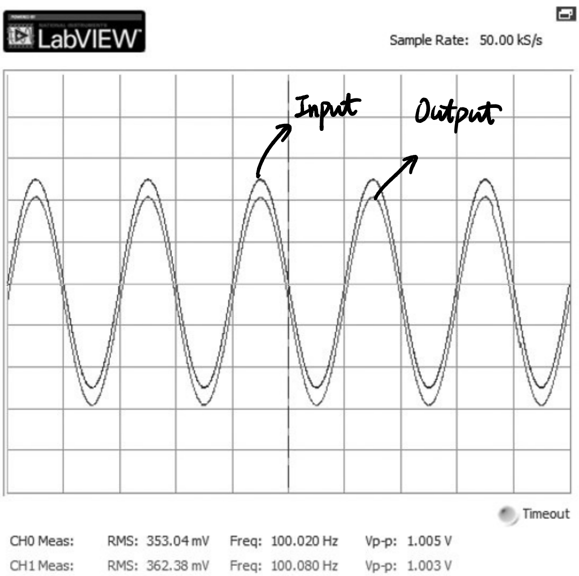
-3dB Point at $f \approx 10$ kHz, phase = 133.381°



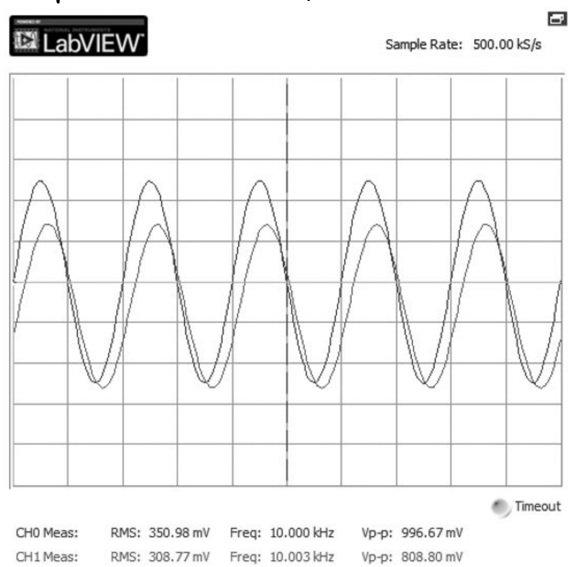
2. Commond mode circuit diagram



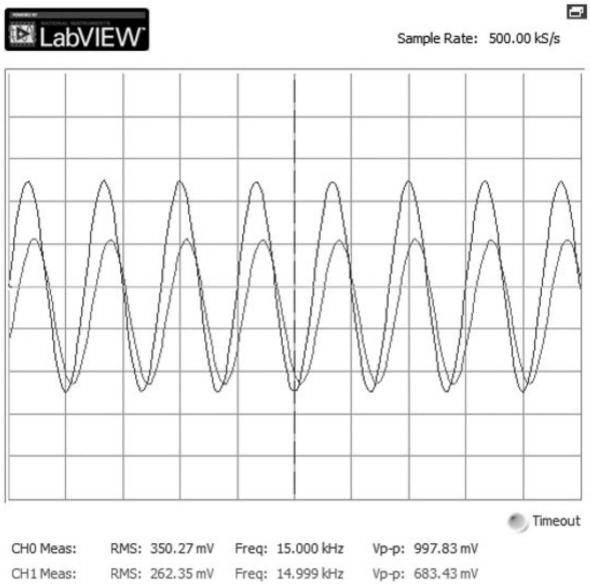
Input 100Hz, 1Vp-p. $A_{100Hz} \approx 0.99\ V/V$



Input 10kHz, 1Vp.p $A_{10kHz} \approx 0.81\ V/V$



Input = 15kHz, 1Vp.p. $A_{15kHz} = 0.68 V/V$

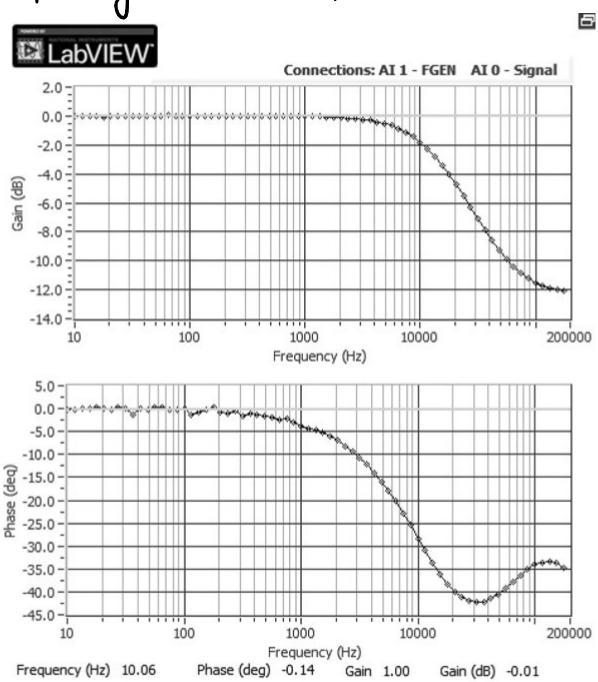


Common mode gain

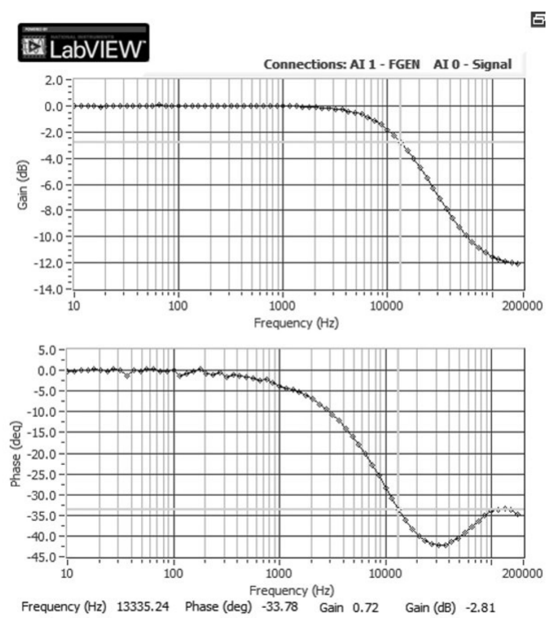
Input f	Gain
100Hz	0.99 V/V ≈ -0.087 dB
10kHz	0.81 V/V ≈ -1.83 dB
15kHz	0.68 V/V ≈ -3.34 dB

Bode Plot on common mode

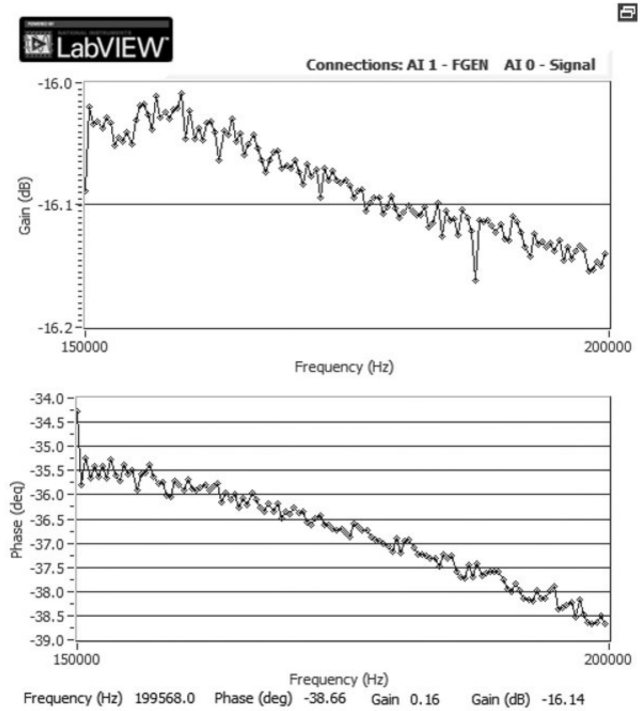
Peak gain at 10Hz A ≈ -0.01 dB



-3dB point at f_0 ≈ 13 kHz A ≈ -2.81 dB

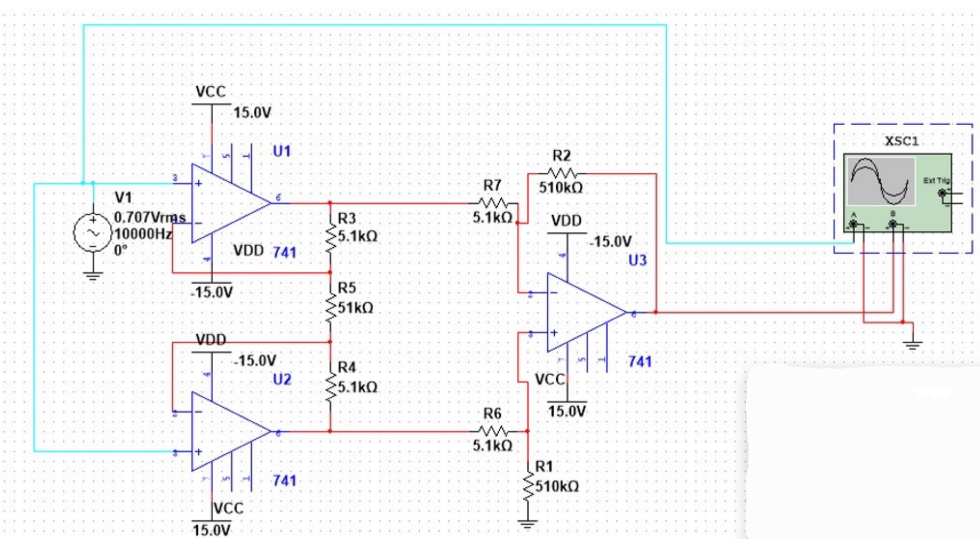


Bode Plot on higher frequency.

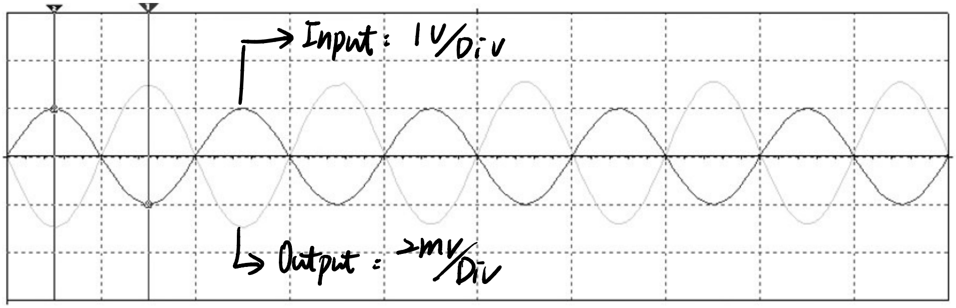


Common mode multisim simulation:

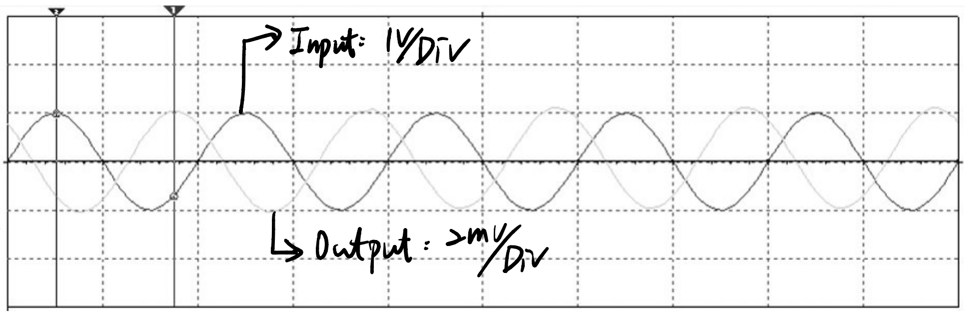
Schematic:



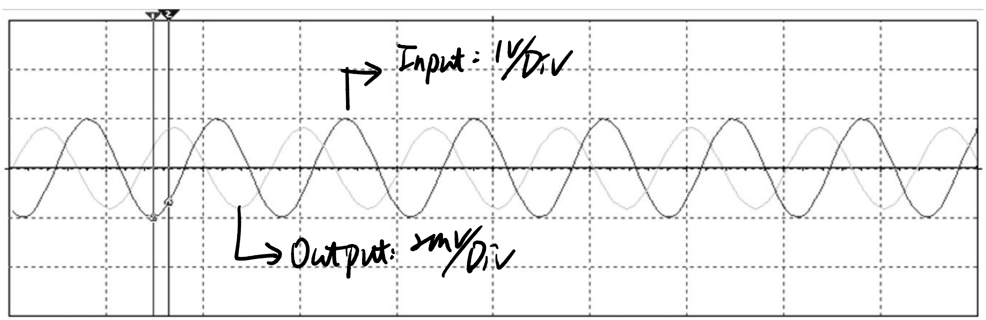
Input
100HZ
2Vp.p
$A \approx 0.003 \frac{V}{V}$
$= -50$ dB



Input
10kHZ
2Vp.p
$A \approx 0.002 \frac{V}{V}$
$= -53$ dB



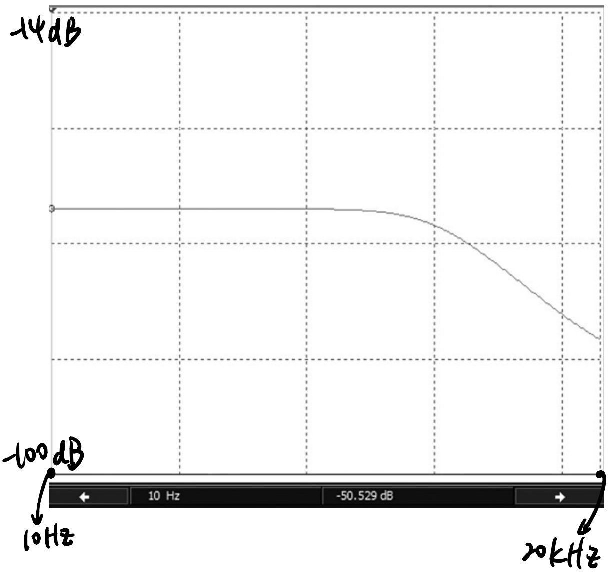
Input
15kHZ
2Vp.p.
$A \approx 0.001 \frac{V}{V}$
$= -60$ dB



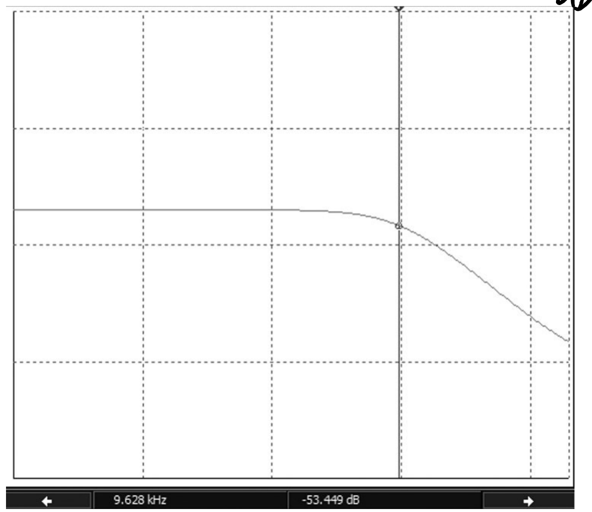
At 3 different frequencies, gains are all less than -50 dB.

Bode Plot - Magnitude Response

Peak gain at 10Hz, A = -50.529 dB

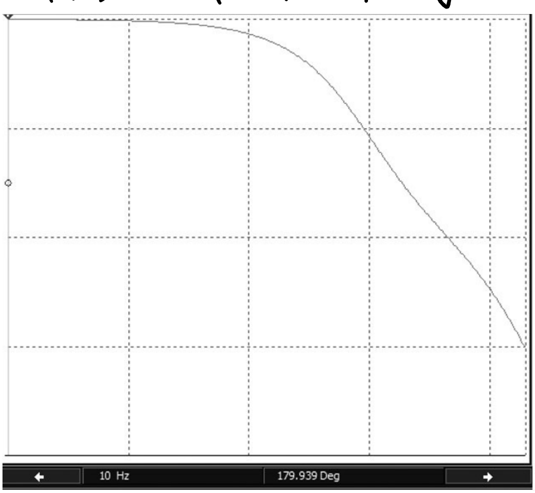


-3 dB point at f_0 = 9628 Hz, A = -53.449 dB

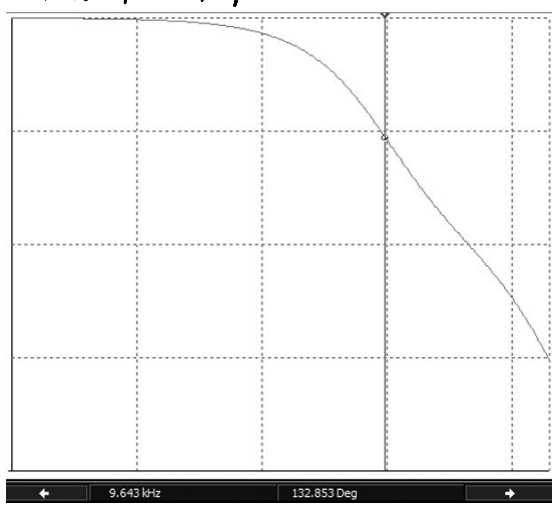


Bode Plot - Phase Response

Phase = 179.939° at peak gain



-3dB point, phase = 132.853°



* Result

Differential Mode:

<a> Physical circuit

f	Gain (V/V)	Bode Plot Gain
100Hz	110	41 dB ≈ 112 (V/V)
10kHz	85	38 dB ≈ 80 (V/V)
15kHz	72	36 dB ≈ 63 (V/V)

<b> Simulation

f	Gain (V/V)	Bode Plot Gain
100Hz	120	41.6 dB ≈ 120 V/V
10kHz	80	38.426 dB ≈ 83.42 V/V
15kHz	60	35.98 dB ≈ 63 V/V

Result of physical and simulation on differential mode are matched.

Common Mode:

<a> Physical circuit

f	Gain (V/V)	Bode Plot Gain
100Hz	0.99	-0.01 dB ≈ 0.99 V/V
10kHz	0.81	-2 dB ≈ 0.79 V/V
15kHz	0.68	-3.5 dB ≈ 0.66 V/V

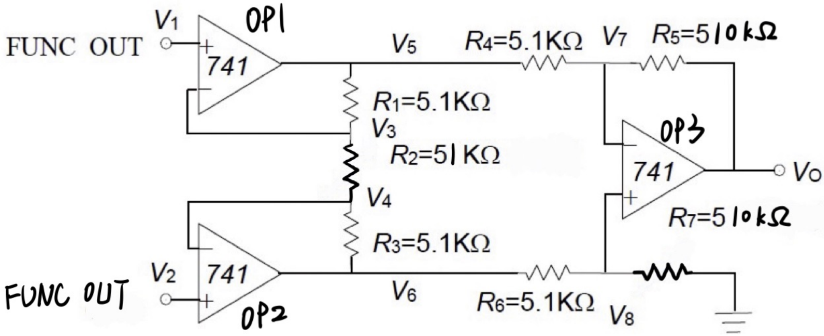
<b> Simulation

f	Gain (V/V)	Bode Plot Gain
100Hz	0.003	-50.529 dB ≈ 0.0029 V/V
10kHz	0.002	-53.449 dB ≈ 0.0021 V/V
15kHz	0.001	-60 dB ≈ 0.001 V/V

Result of physical circuit didn't match the simulation.

Error in common mode:

1°



Connecting the signal from the function generator to physical circuit using the different lenghs of solid wires might cause a propagation delay, which causes a phase shift between two inputs to OP1 and OP2. When subtracting the signal on the last stage differential amplifier, have no the same signal to subtract so the result will be amplified by $R5/R4$, and therefore the output signal will not be ideal.

2°

Using large value of resistors on R5 and R7 might not be a good choice. Since there exists error on resistor value, it might not satisfied the condition $R5/R4 = R7/R6$, so that the last stage will no longer become the differential amplifier.

3°

It is confident that we didn't connect the circuit in the wrong way, since the result of the differential mode is correct. The small change between differential mode and common mode is connect V_2 to function generator.

Question and Discussion:

1. Refer to the datasheet of uA741 Op Amp; please list the parameters of the following, input resistance (輸入電阻), input capacitance (輸入電容), unit-gain bandwidth, and DC gain (直流增益).

Input resistance: ($T_A = 25°C, V_S = \pm 20V$) $\begin{cases} \text{MIN: } 0.3\,M\Omega \\ \text{TYP: } 2\,M\Omega \end{cases}$

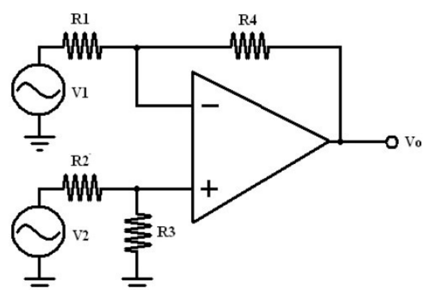
Input capacitance: ($T_A = 25°C$) 1.4 pF

Unit-gain bandwidth: ($T_A = 25°C$) $\begin{cases} \text{MIN: } 0.437\,MHz \\ \text{TYP: } 1.5\,MHz \end{cases}$

DC gain: 106 dB

2. Refer to Figure 1 circuit diagram; if $R_1/R_4 \neq R_2/R_3$, then Vo equals to what?

Using superposition rule:



1° turn off V_2 ($V_+ = V_- = 0$)

$$\Rightarrow \frac{V_1 - \cancel{V_-}^{0}}{R_1} = \frac{\cancel{V_-}^{0} - V_{out-}}{R_4}$$

$$\Rightarrow V_{out-} = -\frac{R_4}{R_1} V_1$$

2° turn off V_1 ($V_+ = V_- = V_2 \cdot \frac{R_3}{R_2 + R_3}$)

$$\Rightarrow V_{out+} = V_2 \frac{R_3}{R_2 + R_3} \left(1 + \frac{R_4}{R_1}\right)$$

3° $V_{out} = V_{out-} + V_{out+}$

$$= -\frac{R_4}{R_1} V_1 + V_2 \frac{R_3}{R_2 + R_3} \left(1 + \frac{R_4}{R_1}\right)$$

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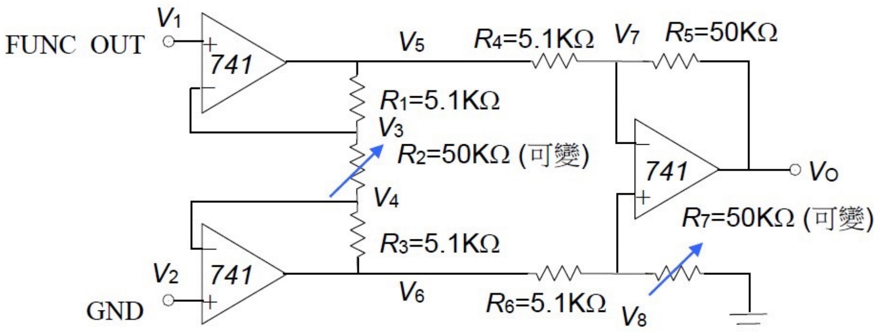
3. Refer to Figure 2 circuit diagram; if the R_2 and R_7 design of the differential amplifier is adjustable, what do R_2 and R_7 mean?



$$A_v = \frac{V_o}{V_2 - V_1} = \left(1 + \frac{2R_1}{R_2}\right) \cdot \frac{R_5}{R_4} \quad \left(\text{if } \frac{R_5}{R_4} = \frac{R_7}{R_6}\right)$$

R_2 is a gain factor in the first stage.

If R_7 no longer match R_5: match or mismatch R_5 to perform different behavior.

4. When building a circuit on the breadboard versus on the printed circuit board (印刷電路板), which circuit board can function at a higher frequency? Why?

Printed circuit board (PCB) can function at a high frequency.

Because high-frequency PCB transmit electromagnetic waves need less energy than breadboard. Also, with low dielectric constant, PCB ensure smooth frequency transmission and minimum signal delay.