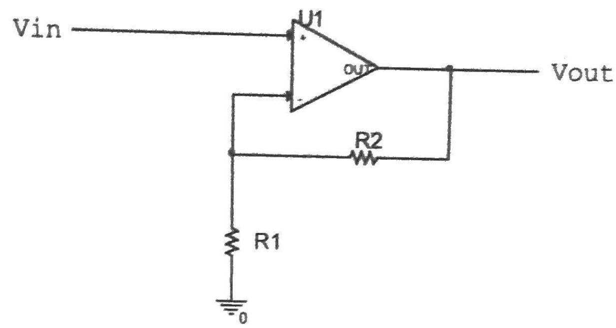
ECSE-2050

Introduction to Electronics
Summer 2020 **Name** ____________________

Homework 4

Reading: Chapter 2.5-2.8

1) Finite Gain



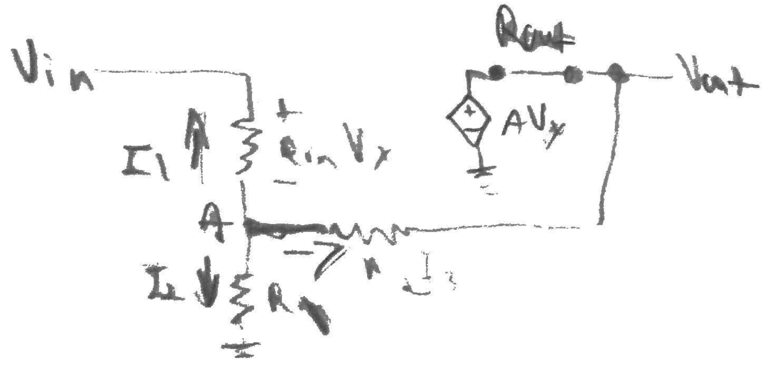
a) Redraw the circuit, replacing the op-amp (not the dashed box) itself with the ideal op-amp dependent source model (Rin $\rightarrow \infty$, Rout $\rightarrow 0$, and $A_{internal} \rightarrow \infty$).

b) Use circuit analysis to determine the relationship between the input and output voltages in terms of R1, R2, and $A_{internal}$.

c) Given the part b result, for an internal op-amp gain of 10^6 and R1 =1k Ω, what value of R2 results in the overall gain, Vout/Vin, being reduced to 90% of its ideal value.

d) Given your part c result, why is the internal gain of the op-amp unlikely to affect the non-inverting amplifier gain under typical usage?

A:



$I_1 + I_2 + I_3 = 0$

$0 + \frac{V_a}{R_1} + \frac{V_a - V_{out}}{R_2} = 0$

$V_{out} = A(V_x) = A(V_{in} - V_a)$

$V_{out} = AV_{in} - AV_a$

$\frac{-(V_{out} - AV_{in})}{A} = V_a$

$\frac{-V_{out} + AV_{in}}{A \cdot R_1} + \frac{-V_{out} + AV_{in}}{R_2 \cdot A} - \frac{V_{out}}{R_2} = 0$

$\frac{-V_{out}}{A \cdot R_1} + \frac{V_{in}}{R_1} - \frac{V_{out}}{R_2 \cdot A} + \frac{V_{in}}{R_2} - \frac{V_{out}}{R_2} = 0$

$V_{in}\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = V_{out}\left(\frac{1}{A \cdot R_1} + \frac{1}{A \cdot R_2} + \frac{1}{R_2}\right)$

B: $\frac{V_{out}}{V_{in}} = \frac{A(R_1 + R_2)}{R_1 + R_2 + AR_1}$

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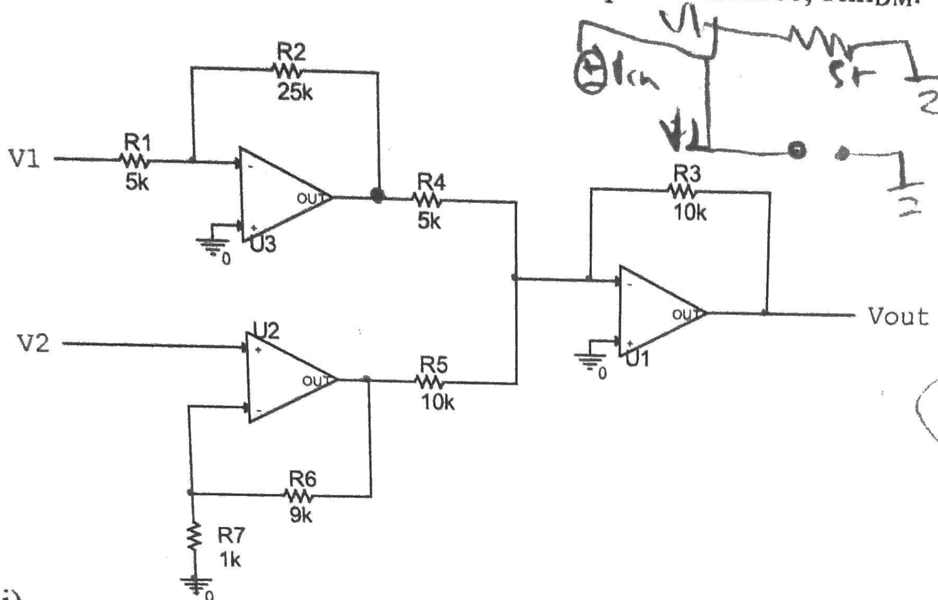
1C: $.9 \frac{V_{out}}{V_{in}} = \frac{10^8(1K + R_2)}{1K + R_2 + 10^9} = .9\left(1 + \frac{R_2}{R_1}\right)$

$R_2 = 1.11 \times 10^8$

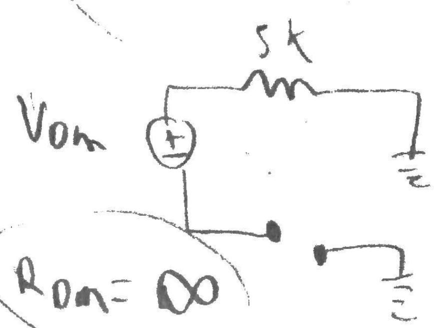
D: To get .9 of the expected ratio you need 10^8 ohms which is functionally open circuit which isn't common.

2) Common mode and differential mode input resistance. Assume the op-amps are ideal.

a)For the two opamp circuits from Homework 2, using methods similar to those used with the difference amplifier, determine the common mode input resistance, Rin_{CM}, and the differential mode input resistance, Rin_{DM}.

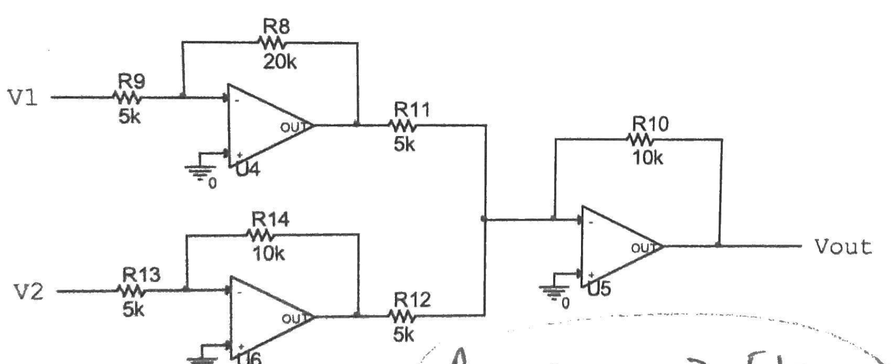


$R_{in\,cm} = 5k$

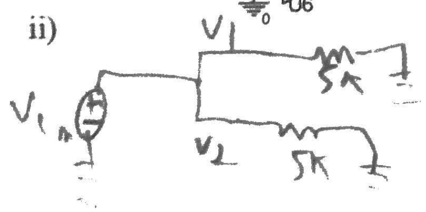


$R_{dm} = \infty$

i)

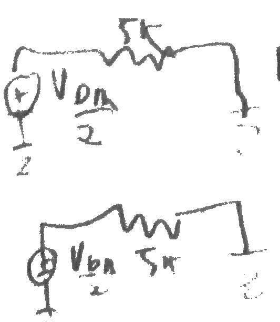


ii)



$R_{in\,cm} = 2.5k$

For V_1:



$R_{dm} = 5k$

in series

$R_{dm} = 10k$

V_2: R_{dm}: 5k

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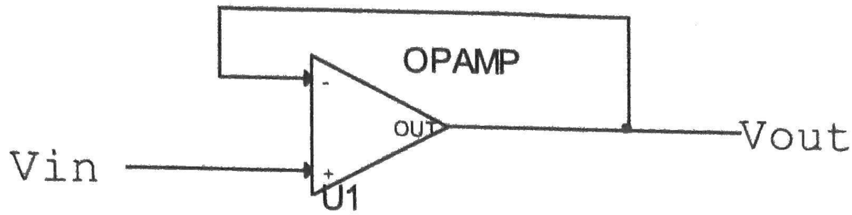
2) Gain Bandwidth Product – Voltage follower transfer function

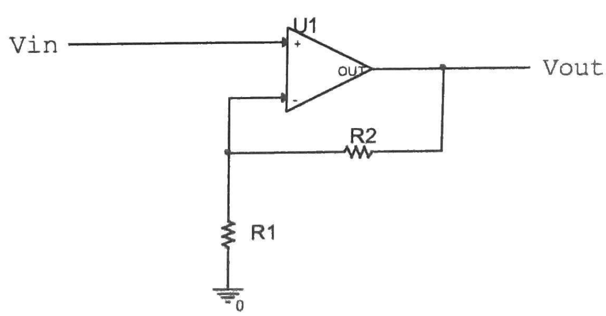


a)For the voltage follower amplifier, the op-amp has apassband internal gain of 10^5 and a break frequency of 10 [rad/s]. Use circuit analysis and the op-amp frequency dependent gain expression, $A(s) = A_{internal}\dfrac{\omega_B}{s+\omega_B}$, to derive the transfer function for the voltage follower, H(s) = Vout(s)/Vin(s) . (You derived the relationship between Vout and Vin for constant finite gain in the last homework.). Make any reasonable simplifications to the transfer function.

b)Based on your transfer function, determine the amplitude of the output voltage when

a. Vin(t) = 10sin(100t) → 10V
b. Vin(t) = 10sin(10^5t) → 10 V
c. Vin(t) = 10sin(10^7t) → 1V

(pay attention to the amplitude of the input voltage, 10V)



c) Using your problem 1 expression, substitute the frequency dependent expression for op-amp gain, $A(s) = A_{opamp}\dfrac{\omega_B}{s+\omega_B}$, and determine the low pass filter transfer function for the non-inverting amplifier.

d) For R1 = 1kΩ, R2 = 9kΩ, and the same op-amp characteristics as part a, make reasonable simplifications to the transfer function and determine the cutoff frequency of the non-inverting amplifier.

$$A = \frac{\frac{A_w}{s+w}}{\frac{A_w}{s+w}+1} \rightarrow H(s) = \frac{A_{int}\,\omega_B}{A_{int}\,\omega_B + s + \omega_B} = \frac{10^6}{10^6+10+s} = \frac{10^6}{10^6+s}$$

3 C:

$$\frac{V_{out}}{V_{in}} = \frac{A(R_1 + R_2)}{R_1 + R_2 + AR_1} = \frac{\frac{A\omega_B}{s+\omega_B}(R_1 + R_2)}{R_1 + R_2 + \frac{A\omega_B}{s+\omega_B}R_1}$$

$$H(s) = \frac{A\omega_B(R_1 + R_2)}{R_1(s+\omega_B) + R_2(s+\omega_B) + Ar_1\omega_B}$$

D:

$$H(s) = \frac{10^{10}}{10^3 s + 10^4 + 9\times10^3 s + 9\times10^4 + 10^9}$$

$$= \frac{10^{10}}{10^4 s + 10^9} = \frac{10^{10}}{10^4(s+10^5)} = \frac{10^6}{s+10^5} = H(s)$$