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Tristan Denning

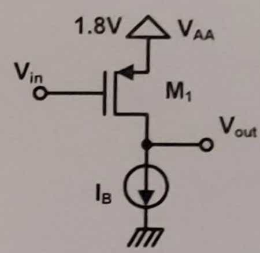
ECE 310 – Microelectronics I

Prof. Suat Ay **Homework #6** *Fall 2021*

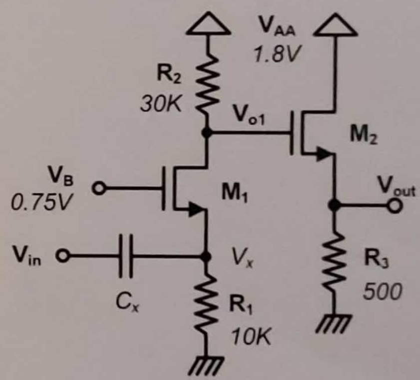
(Due Date: 11/05/2021, 8.30am)

For the problems 1 &2, use: KP_n=100 μA/V², KP_p=50 μA/V², $V_{THn}=|V_{THp}|$=0.5V, λ_n=0.05, λ_p=0.1

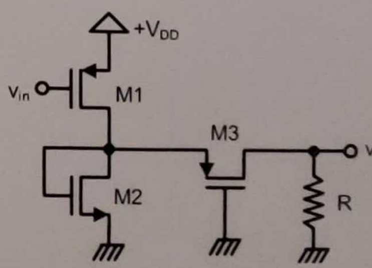
1. (20pts) A common source (CS) amplifier will be designed. Assume M_1 is biased 100mV in ON region, V_{DSAT1}=0.8V, and I_B=20μA.
   a. (15pts) Find $V_{in(DC)}$, $V_{out(DC)}$, and $(W/L)_1$ values.
   b. (10pts) Find small signal voltage gain (A_v) expression and calculate its value.



2. (55pts) Following is a multi stage amplifier. Assume; I_{ds2}=1mA and $V_{X,DC}$=0.2V by design.
   a. (18pts) Find, I_{ds1}, V_{od1}, V_{dsat1}, $V_{o1(DC)}$, $(W/L)_1$, $(W/L)2$, and V_{od2}, V_{dsat2}, $V_{out(DC)}$, values.
   b. (12pts) Draw the small signal equivalent circuit (SSEC).
   c. (15pts) Find small signal voltage gains $A_{v1}=v_{o1}/v_{in}$, $A_{v2}=v_{out}/v_{o1}$, and overall voltage gain ($A_v=v_{out}/v_{in}$) of the amplifier.
   d. (10pts) What would be the Cx capacitor value chosen so that this circuit can accept any signal that has frequency higher than 100Hz.



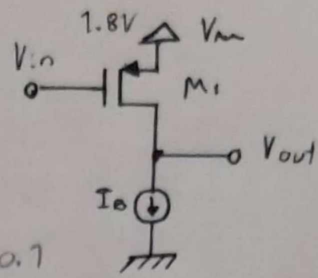
3. (35 pts) Analyze following amplifier. Use; g_{m1}=10 mS, g_{m2}=1mS, g_{m3}=4mS, R=1Kohm



   a. (10pts) Draw small signal equivalent circuit for λ=0
   b. (10pts) Find small signal output resistance expression and its value, R_{OUT}=?
   c. (10pts) Find small signal transconductance expression and its value, G_m=?
   d. (5pts) Find small signal voltage gain expression, and calculate its value, Av=?

Tristan Denning | ECE-310 Homework 6 Problem 1(a) | HW # 06

1(a) 1. Situation: Design a Common Source (CS) Amplifier. Assume M_1 is biased 100mV in ON Region, $V_{DSAT} = 0.8V$, $I_B = 20\mu A$. a.) Find $V_{in(DC)}$, $V_{out(DC)}$, and $(W/L)_1$ Values.

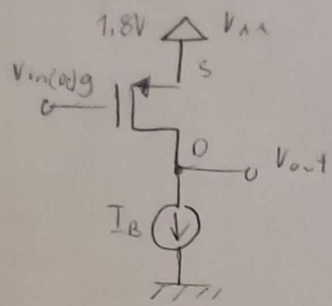


Given: $KP_n = 100\ \mu A/V^2$, $KP_p = 50\mu A/V^2$,
$V_{TH_n} = |V_{TH_p}| = 0.5V$, $\lambda_n = 0.05$, $\lambda_p = 0.1$

2. **Goal:** To Find / calculate Values For $V_{in(DC)}$, $V_{out(DC)}$, and $(W/L)_1$.

3. **Plan:** To use Known / Given Transistor equations to determine $V_{(in)DC}$, $V_{out,(DC)}$ and $(W/L)_1$ For the given PMOS CS Amplifier

4. **Solution:** Redraw:



Observe:

$V_g = V_{in}$

$V_s = V_{AA} = 1.8V$

$V_D = V_{out}$

$I_B = I_{SD} = 20\times10^{-6} A$

Overdrive Voltage: $V_{OD} = V_{SG} - |V_{TH}|$

$0.1 = V_{SG} - 0.5$ $\qquad \therefore V_{OD} = 0.1$, *Given

$\therefore V_{SG} = 0.6V$

KVL $V_{AA} - V_{SG} - V_{in(DC)} = 0$

$1.8 - 0.6 = V_{in(DC)}$

$\therefore \boxed{V_{in(DC)} = 1.2V}$

Saturation Voltage:

$V_{D,SAT} = V_{SD} - V_{OD}$

$0.8 = V_{SD} - 0.1$

$\therefore V_{SD} = 0.9V$

$V_{SD} = V_S - V_D$

$0.9 = 1.8 - V_D$

$V_D = V_{out(DC)}$

$\therefore \boxed{V_{out(DC)} = 0.9V}$

1/20

$\boxed{1(a)}$ (Continued)

SAT PMOS I_{SD}

$$I_{SD} = \tfrac{1}{2} KP_p \left(\tfrac{W}{L}\right)_1 (V_{OD})^2 (1 + \lambda V_{SD})$$

$$20\times10^{-6} = 0.5(50\times10^{-6})\left(\tfrac{W}{L}\right)_1 (0.1)^2(1+0.1(0.9))$$

$$\therefore \left(\tfrac{W}{L}\right)_1 = \frac{2(20\times10^{-6})}{(50\times10^{-6})(0.1)^2(1+0.1(0.9))}$$

$$\boxed{\left(\tfrac{W}{L}\right)_1 = 73.39}$$

5 Sanity Check

Check KVL's

$$V_{AA} = V_{out(DC)} + V_{GD} + V_{SG}$$

$$1.8 = 0.9 + (1.2 - 0.9) + 0.6$$

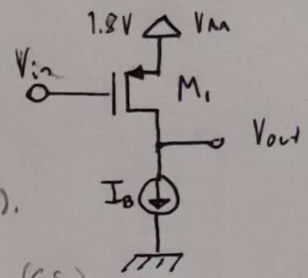
$$1.8 = 1.8 \quad \checkmark$$

$$V_{AA} - V_{SD} - V_{out(DC)} = 0$$

$$1.8 - 0.9 - 0.9 = 0 \quad \checkmark$$

$\boxed{1(b)}$

1 Situation: Design a (CS) Amplifier. Assume M_1 is biased 700mV ON, $V_{O,SAT} = 0.8V$, $I_B = 20\mu A$. b.) Find small signal gain (A_v) expression and calculate its value. Use same given characteristic parameters as in 1(a).

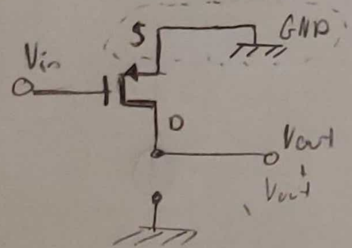


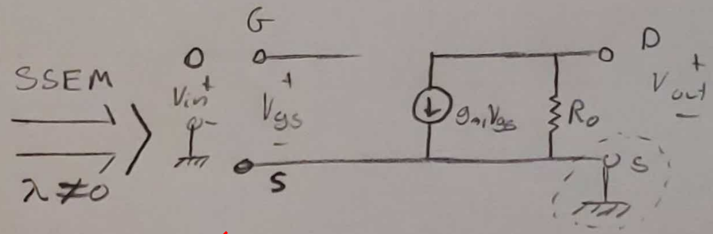
2 Goal: To derive an expression for the given (CS) Amplifier's Gain (A_v), then calculate its value.

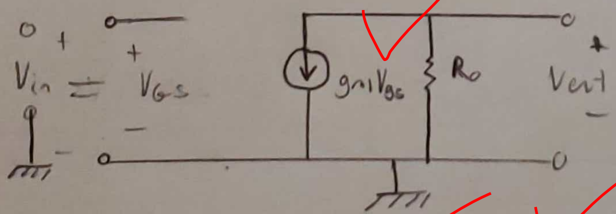
3 Plan: To find the small signal equivalent model for the CS Amp, then follow the procedure for determining A_v. Then plug in known / calculated values to evaluate A_v.

4 Solution

Redraw $\Rightarrow$ DC components $= 0$



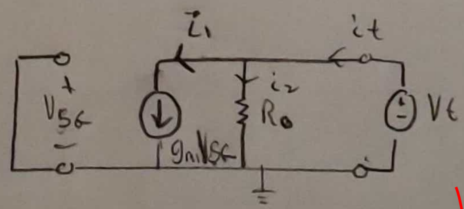




Voltage Gain: $= Z_{out} \cdot G_m = R_{out} \cdot G_m$

Find R_{out}: Solve $R_{out} = V_t / I_t \big|_{R_{in} = 0}$, V_t on output

Redraw



$V_{SG} = 0$

$\therefore i_1 = 0$

$i_2 = i_t$

$$\therefore R_{out} = R_o = \frac{1}{\lambda I_{SD}}$$

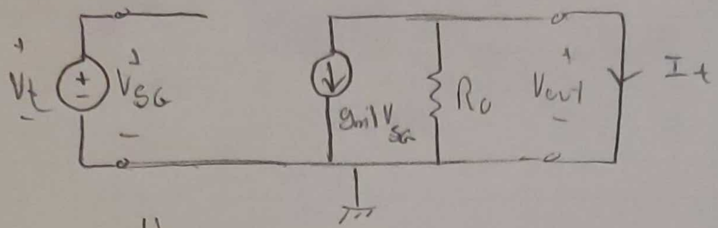
(*) Lect 26

$\boxed{1(b)}$ (continued)

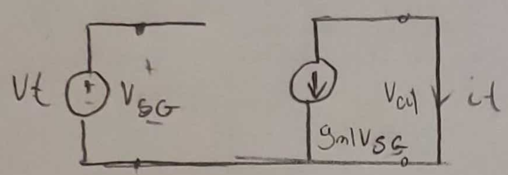
Find G_m, Place V_t between input Ports, Short output

Solve $G_m = i_t / v_t \big|_{R_L = 0}$

Redraw:



$\Downarrow$



$$i_t = -g_{m1} V_{SG}$$
$$V_t = V_{SG}$$
$$i_t / v_t = -g_{m1}$$

$$\therefore G_m = -g_{m1}$$

$$G_m = \frac{-2 I_{SD}}{(V_{SG} - V_{TH})}$$

* Lect 27

Find A_v

$$A_v = R_{out} \cdot G_m$$
$$= \left(\frac{1}{\lambda I_{SD}}\right) \frac{2 I_{SD}}{(V_{SG} - V_{TH})}$$

$$\boxed{A_v = \frac{-2}{\lambda (V_{SG} - V_{TH})}}$$

Evaluate:

$$A_v = \frac{-2}{0.1(0.6 - 0.5)}$$

$$\boxed{A_v = -200}$$

Sanity Check:

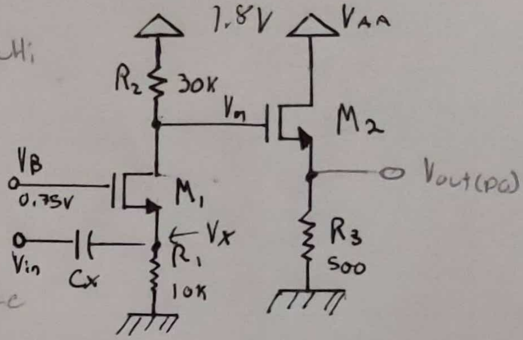
$$g_m = KP_p (W/L)(V_{SG} - V_{TH})(1 + \lambda V_{SD}) = \frac{2 I_{SD}}{(V_{SG} - V_{TH})}$$
$$= 50 \times 10^{-6} (73.39)(0.1)(1 + 0.1(0.9)) = \frac{2(20 \times 10^{-6})}{0.1}$$
$$= 0.0004 \qquad = 0.0004 \checkmark$$

$\boxed{4/20}$

2(a)

1 **Situation:** The following is a multi stage amplifier. Assume $I_{DS2} = 1mA$ and $V_{X,DC} = 0.2V$. Use same given transistor characteristics as 1(a.).

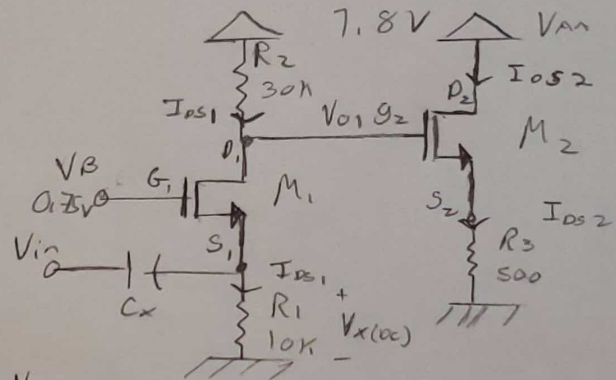
a.) Find I_{DS1}, $V_{OD,1}$, V_{DSAT1}, V_{O1}, $(W/L)_1$, $(W/L)_2$, V_{OD2}, V_{DSAT2}, $V_{out(DC)}$ values.



2 **Goal:** To determine the values for the quantities listed above.

3 **Plan:** To use known transistor voltage and current expressions along with the fundamental theorems of circuit analysis to find / calculate values for the above stated quantities.

4 **Solution:**



Given: $I_{DS2} = 0.001A$

$V_X = 0.2V$

Observe: $V_{D1} = V_{G2} = V_{o1}$

$V_{S1} = V_X = 0.2V$

$V_{o1} = V_{G2}$

I_{DS1} $\quad I_{R_1} = I_{DS1} = V_{X(DC)}/R_1$ $\quad \therefore$ Ohms law R_1

$= \frac{0.2}{10000}$

$$\boxed{I_{DS1} = 2\times10^{-5}\ A = 20\ \mu A}$$

$\therefore V_{R_2} = I_{DS1}(R_2)$

$= 20\times10^{-6}(30000)$

$V_{R_2} = 0.6V$

$\therefore V_{DS1} = V_{AA} - V_{X(DC)} - V_{R_2}$ $\quad$ KVL $\rightarrow M_1$

$= 1.8 - 0.2 - 0.6$

$V_{DS1} = 1\ V$

$\therefore V_{o1(DC)} = V_{X(DC)} + V_{DS1}$

$= 0.2 + 1$

$$\boxed{\therefore V_{o1(DC)} = 1.2\ V}$$

$\boxed{5/20}$

$\boxed{2(a)}$ (Continued)

$\underline{V_{OD_1}}$

$V_{G_1} = V_B = 0.75$

$V_{S_1} = V_{x(DC)} = 0.2V$

$\therefore V_{GS_1} = 0.55 V$

$V_{OD_1} = V_{GS_1} - V_{TH,n}$ * Lect 23, S2

$= 0.55 - 0.5$

$\boxed{V_{OD1} = 0.05 V}$

$\underline{V_{DSAT,1}}$

$V_{DSAT_1} = V_{DS_1} - V_{OD_1}$ * Lect 23, S2

$= 1 - 0.05$

$\therefore \boxed{V_{DSAT_1} = 0.95 V}$

$\underline{(W/L)_1}$

$I_{DS_1} = \frac{1}{2} KP_n (W/L)_1 (V_{OD_1})^2 (1 + \lambda V_{DS})$

$(W/L)_1 = \frac{2 I_{DS1}}{(KP_N)(V_{OD_1})^2 (1+\lambda V_{DS})}$

$= \frac{(20 \times 10^{-6}) \cdot 2}{(100 \times 10^{-6})(0.6^2)(1 + 0.05 \cdot 1)}$

$\boxed{(W/L)_1 = 1\cancel{5}2.38}$

$\underline{V_{out(DC)}}$

$V_{out(DC)} = V_{R_3} = I_{DS2}(R_3)$ Ohm's law R_3

$= 0.001(500)$

$\therefore \boxed{V_{out(DC)} = 0.5V}$

$= V_{S2}$

$V_{G2} = V_{DC} = 1.2V$ * KVL

$V_{OD_2} = V_{GS_2} - V_{TH,N}$

$= (1.2 - 0.5) - 0.5$

$\boxed{V_{OD2} = 0.2 V}$

$\boxed{6/20}$

$\boxed{2(a)}$ (Continued)

$\underline{V_{DSAT_2}}$

$$V_{DSAT2} = V_{DS2} - V_{OD1}$$

$$V_{DS2} = V_{D2} - V_{S2}$$

$$= V_{AA} - V_{out(DC)}$$

$$= 1.8 - 0.5V$$

$$V_{DS2} = 1.3V$$

$$\therefore V_{DSAT2} = 1.3 - 0.2$$

$$\boxed{V_{DSAT2} = 1.1\ V}$$

$\underline{\left(\frac{W}{L}\right)_2}$

$$I_{DS2} = \frac{1}{2} KP_N \left(\frac{W}{L}\right)_2 (V_{OD2})^2 (1 + \lambda V_{DS2})$$

$$\left(\frac{W}{L}\right)_2 = \frac{2 I_{DS2}}{KP_N \cdot (V_{OD2})^2 (1 + \lambda V_{DS2})}$$

$$= \frac{2(0.001)}{100\times10^{-6} (0.2)^2 (1 + 0.05 \cdot 1.3)}$$

$$\boxed{\therefore \left(\frac{W}{L}\right)_2 = 469.484}$$

5 Sanity Check

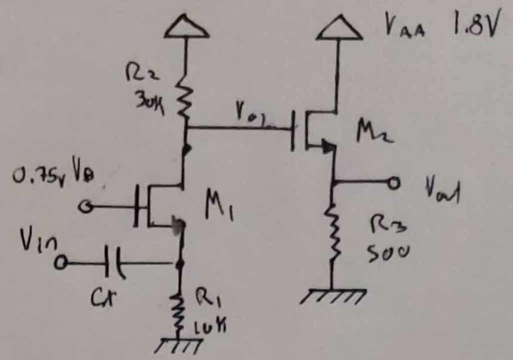
Check KVL's

$$V_{S2} + V_{GS2} - V_{DS1} - V_{S1} = 0$$
$$0.5 + 0.7 - 1 - 0.2 = 0$$
$$1.2 - 1.2 = 0$$
$$0 = 0$$

(*) Answers are reasonable and dependent on eachother, and KVL is fulfilled

$\boxed{7/20}$

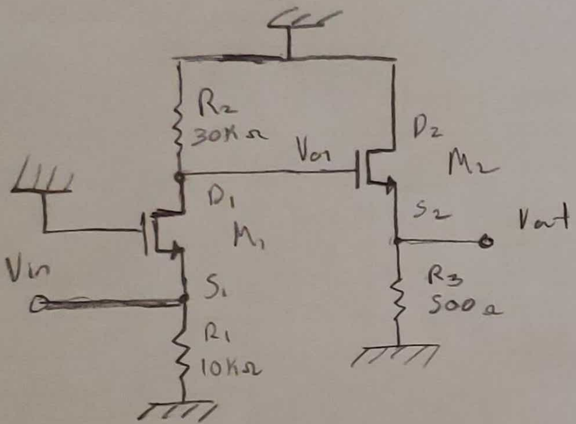
2(b) 1 Situation: For the multistage amplifier described in 2(a.):
b.) Draw the small signal equivalent circuit SSEC.



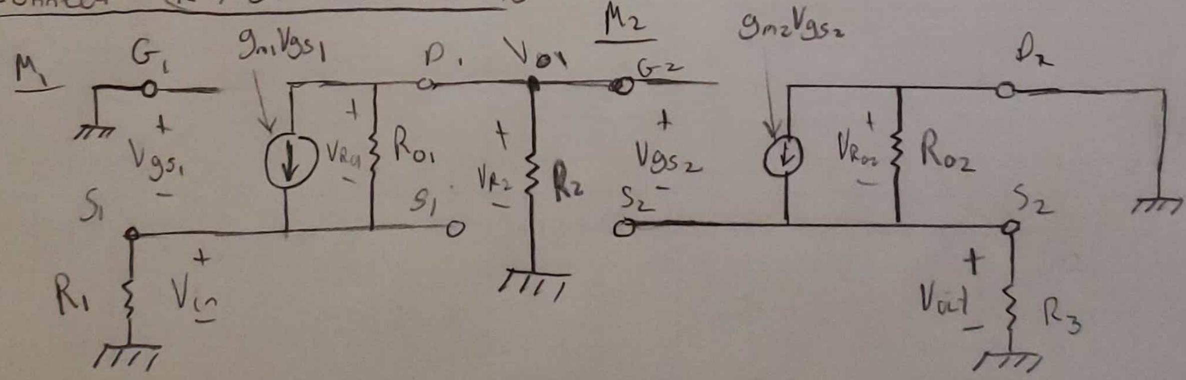
2 Goal: To create a small signal equivalent model for the given multistage amplifier.

3 Plan: To mesh the generic SSEM ($\lambda \neq 0$) models for each of the transistors with the architecture of the amplifier to creat an overall model to perform small signal analysis.

4 Solution: Redraw – Set all DC components to 0.



Connect ($\lambda \neq 0$) SSE models

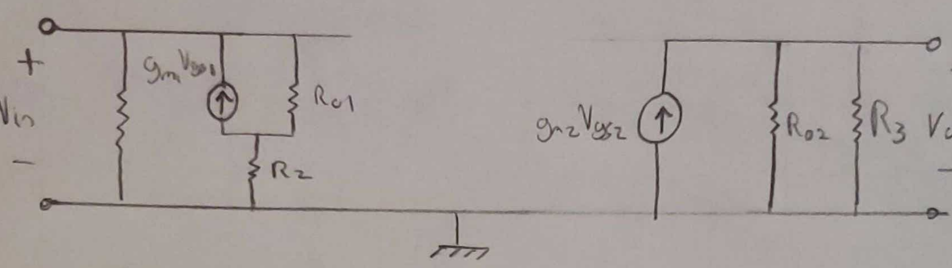


Useful KVL's

$V_{in} = V_{R_1} = -V_{GS_1}$
$V_{in} + V_{Ro_1} = V_{R_2}$
$V_{R_2} = V_{o1} - V_{out} = V_{GS2}$
$V_{o1} = V_{R_2}$

2(b) (continued)

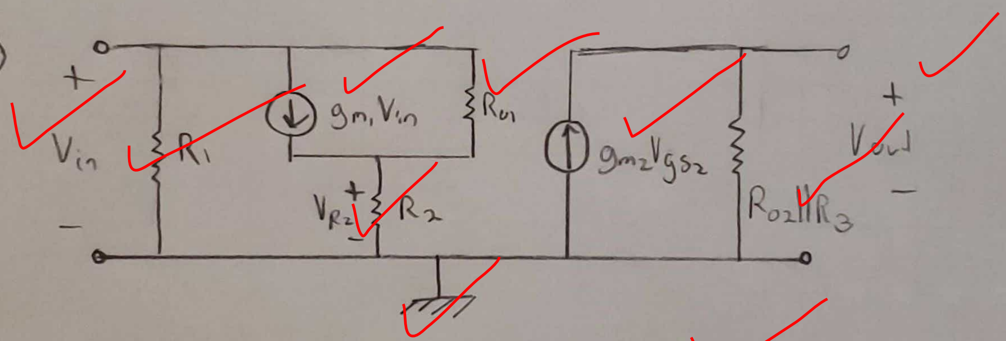
Simplify / Clean up



Apply $V_{gs1} = -V_{in}$ and $V_{gs2} = V_{o1} - V_{out}$

Combine $R_{o2} || R_3$

$\Longrightarrow$



Apply $R_1 = 10K$, $R_2 = 30K$, $R_3 = 500K$

$$R_{o1} = \frac{1}{\lambda_N I_{DS1}} = 1000000\ \Omega = 1M\Omega$$

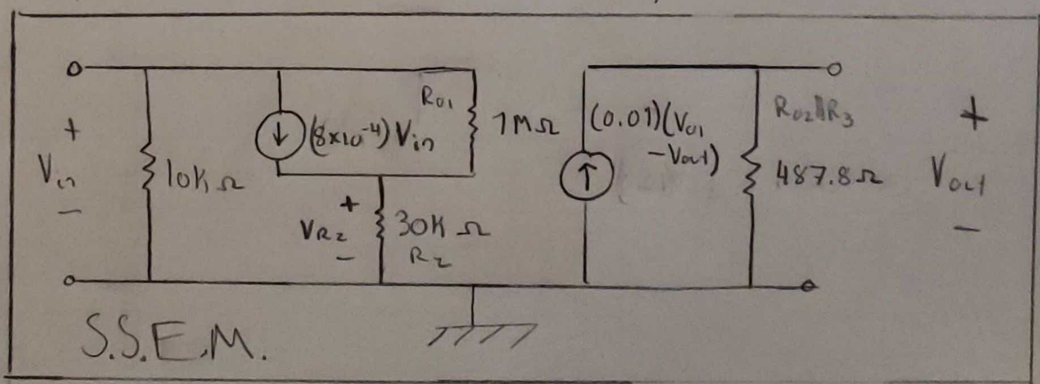
$$R_{o2} = \frac{1}{\lambda_N I_{DS2}} = 20K\ \Omega$$

$$\therefore\ R_{o2} || R_3 = 487.8\ \Omega$$

$$g_{m1} = \frac{2I_{D01}}{V_{OD1}} = 8\times10^{-4}$$

$$g_{m2} = \frac{2I_{D02}}{V_{OD2}} = 0.01$$

$\Longrightarrow$



$\boxed{2(b)}$ (Continued)

5 Sanity Check

Useful KVL'S Are Fulfilled in all iterations of the circuit.

$$V_{out} = V_{Ro2} = V_{R3} = V_{g_{m2}V_{R2}} \quad \checkmark$$

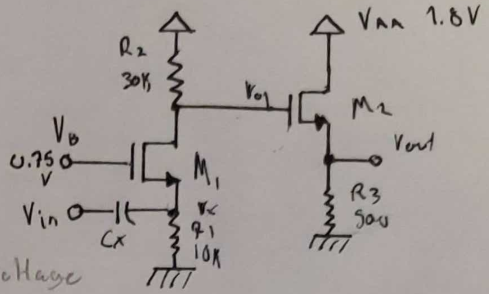
$$V_{in} + V_{g_{m1}V_{in}} - V_{R2} = 0 \quad \checkmark$$

$$V_{in} = V_{Ro1} + V_{R2} \quad \checkmark$$

$$V_{gs2} = V_{Ro1} - V_{out} \quad \checkmark$$

$\boxed{10/20}$

$\boxed{2(c)}$ 1. **Situation**: For the SSEM Determined in 2(b), C.) Find the Small Signal Voltage Gains $A_{v_1} = V_{o1}/V_{in}$, $A_{v_2} = V_{out}/V_{o1}$, and overall Voltage gain, A_v, of the amplifier

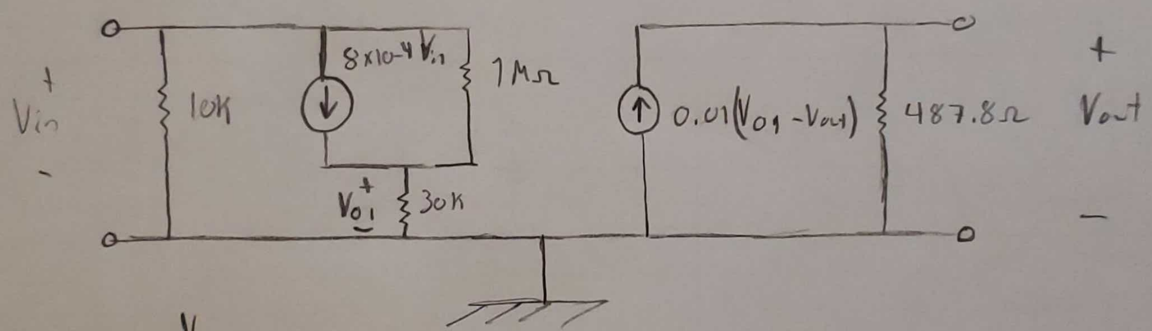


2. **Goal**: To determine the Small signal Voltage gains as defined above.

3. **Plan**: Use the $V_{o1} = V_{R_2}$ determined in 2(b) along with Fundamental circuit analysis techniques to Determine expressions for A_{v_1}, A_{v_2} and $A_{v_1} \times A_{v_2} = A_v$.

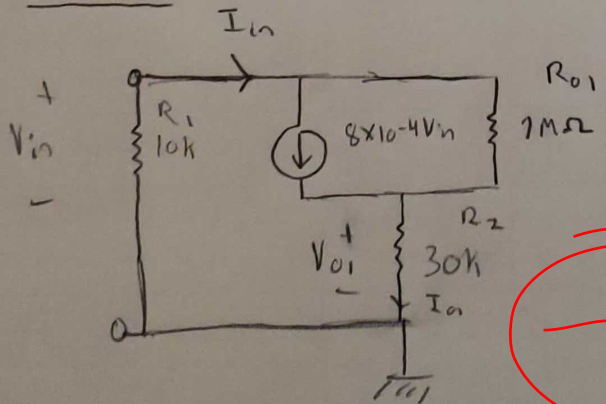
4. **Solution**: Redraw SSEM

$V_{R_2} = V_{o1}$ (From 2(b))



$$A_{v_1} = \frac{V_{o1}}{V_{in}}$$

Left Side



KCL.) $I_{in} = I_{o1}$

$$\frac{-V_{in}}{R_1} = \frac{V_{o1}}{R_2}$$

$$\therefore \frac{V_{o1}}{V_{in}} = \frac{-R_2}{R_1}$$

$$= -\frac{30000}{10000}$$

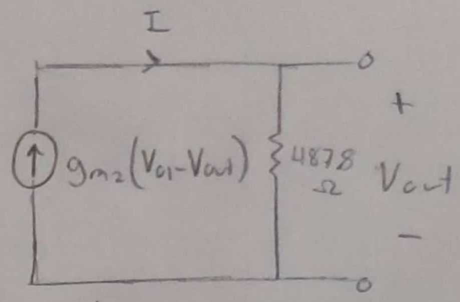
−5

$$\therefore \boxed{A_{v_1} = \cancel{-3}}$$

$\boxed{2(c)}$ (Continued)

$$A_{v2} = \frac{V_{out}}{V_{o1}}$$

Right Side:



Ohm's law, $V_{out} = I\,(487.8)$

$$V_{out} = g_{m2}(V_{o1} - V_{out})(487.8)$$

$$V_{out} = 487.8\, g_{m2} V_{o1} - 487.8\, g_{m2} V_{out}$$

$$V_{out}(1 + 487.8\, g_{m2}) = V_{o1}(487.8\, g_{m2})$$

$$\frac{V_{out}}{V_{o1}} = \frac{(487.8\, g_{m2})}{(1 + 487.8\, g_{m2})}$$

$$= \frac{4.878}{5.878} \qquad \because g_{m2} = 0.01$$

$$\boxed{A_{v2} = 0.8298}$$

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

$$\frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_{o1}} \cdot \frac{V_{o1}}{V_{in}} = A_{v1} \cdot A_{v2}$$

$$\therefore A_v = A_{v1} \cdot A_{v2} = -\cancel{3} \cdot 0.8298$$

$$\boxed{A_v = -\cancel{2.49}}$$

−1

5 Sanity Check:

A_v Unit Analysis $\quad A_v = A_{v1} \times A_{v2} \qquad [-]$

$$= \frac{R_2}{R_1} \times \frac{487.8\, g_{m2}}{1 + 487.8\, g_{m2}}$$

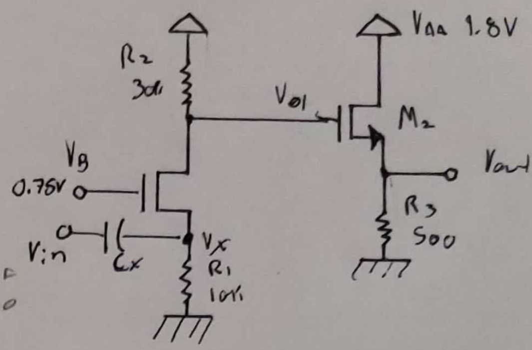
$$= \frac{[\Omega]}{[\Omega]} \times \frac{[1/\Omega]}{\left[\frac{1}{\Omega}\right]}$$

$$= [-]$$

$\boxed{12/20}$

$\boxed{2(d)}$

1 **Situation:** For the given multistage amplifier d.) What would be the Cx Value for the circuit to accept any Signal with a frequency over 100 Hz ?



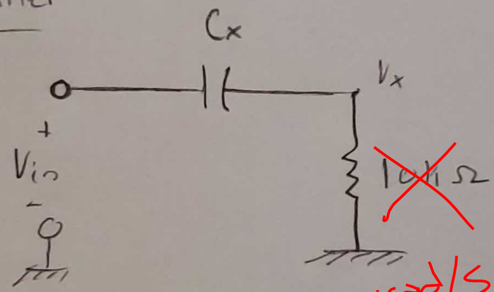
2 **Goal:** Determine the capacitance of Cx to allow the amplifier to take a signal with $f \geq 100$ Hz.

3 **Plan:** To use the high-pass filter equation (From Lecture 28 Slide 9) to solve for Cx, given frequency and drain resistence.

4 **Solution:**

-8

High-Pass-Filter



rad/s   1/s

Given $f = 100$ Hz $\therefore \omega = 200\pi$ Hz

Eqn $\omega_{BW} = \dfrac{1}{R_{in} C_x}$

2π f

$\therefore C_x = \dfrac{1}{R_{in}\,\omega_{BW}} = \dfrac{1}{(200\pi)(\cancel{10000})}$

$\boxed{C_x = \cancel{159.2\text{ nF}}}$

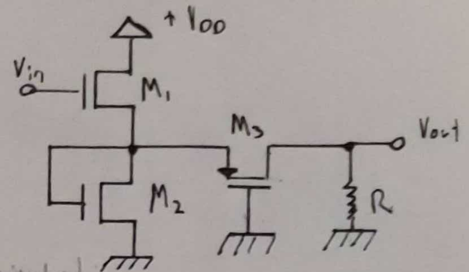
5 **Sanity Check:**

$100 = \dfrac{1}{(10000)(159.2\times10^{-9})\,2\pi}$

$100 \cong 99.97$ ✓

Cx is rounded, but yields ~ $f = 100$ Hz

3(a) 1. **Situation:** Analyze the following amplifier. Use $g_{m1} = 10mS$, $g_{m2} = 1mS$, $g_{m3} = 4mS$, $R = 1k\Omega$. a.) Draw the Small Signal equivalent Circuit for $\lambda = 0$.

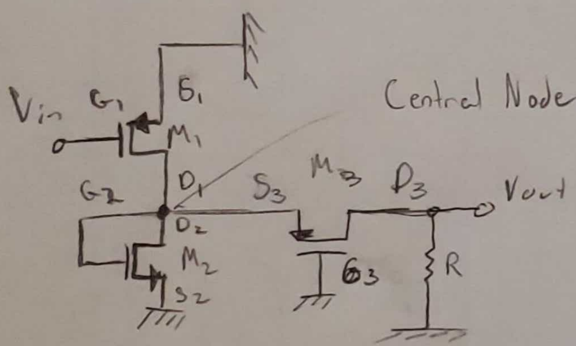


2. **Goal:** To Develop the Small Signal equivalent Circuit for the given amplifier with the given g_m and R Values.

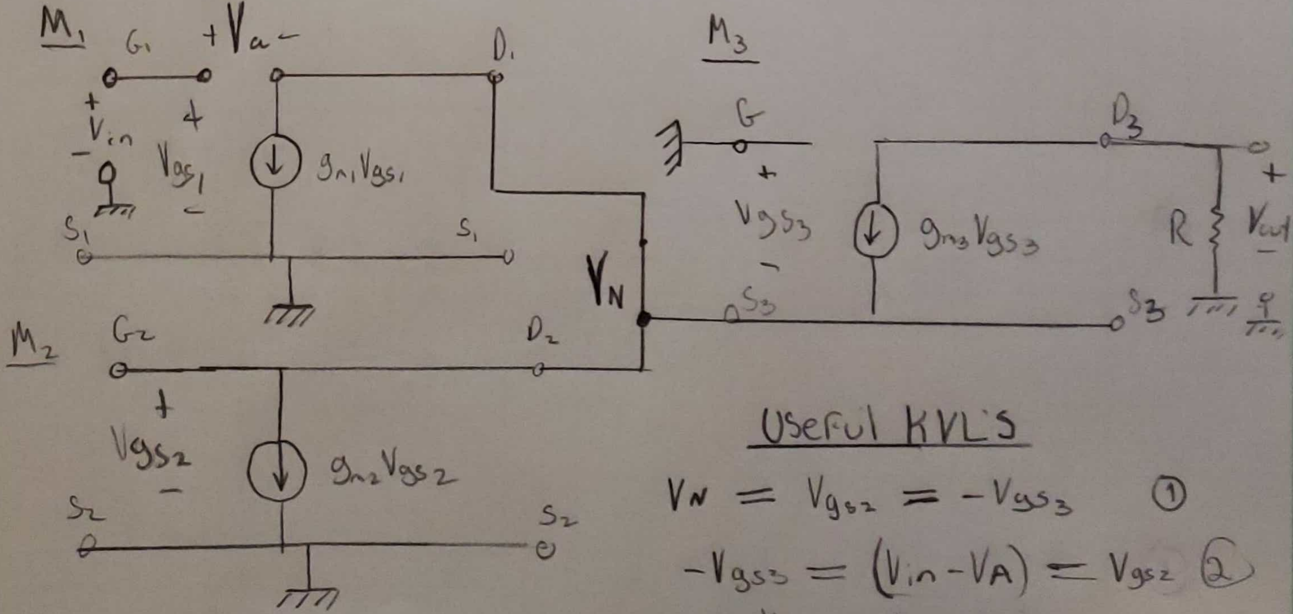
3. **Plan:** To make all DC components = 0, then use the generic ($\lambda = 0$) model for M_1, M_2, M_3. Then Connect each model in accordance with the given architecture and simplify.

4. **Solution:**

Force all DC's to Zero



Convert to $\lambda = 0$ model



Useful KVL'S

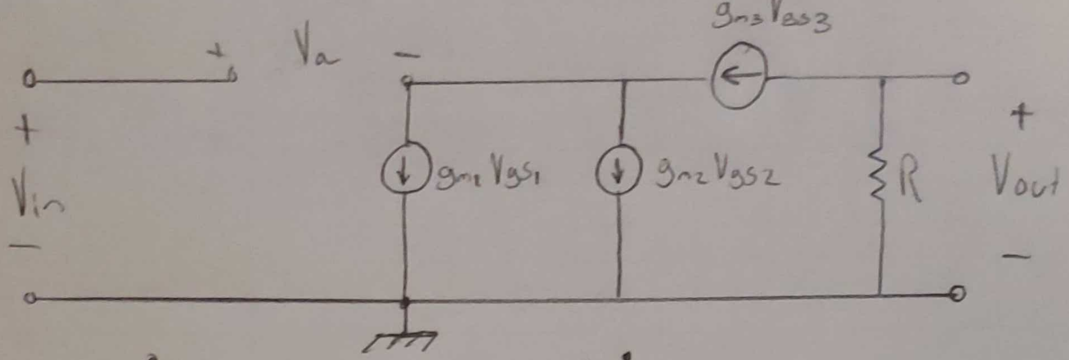
$$V_N = V_{gs2} = -V_{gs3} \quad (1)$$

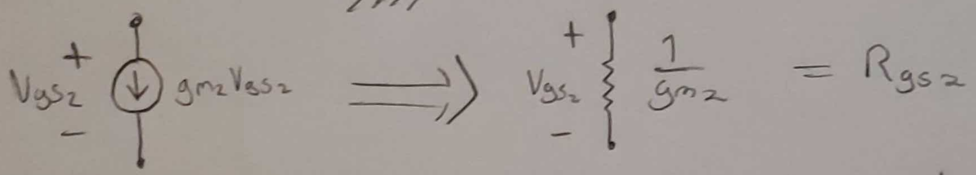
$$-V_{gs3} = (V_{in} - V_A) = V_{gs2} \quad (2)$$

$$V_{gs1} = V_{in}$$

$\boxed{3(a)}$ (continued)

Simplify / Draw Properly



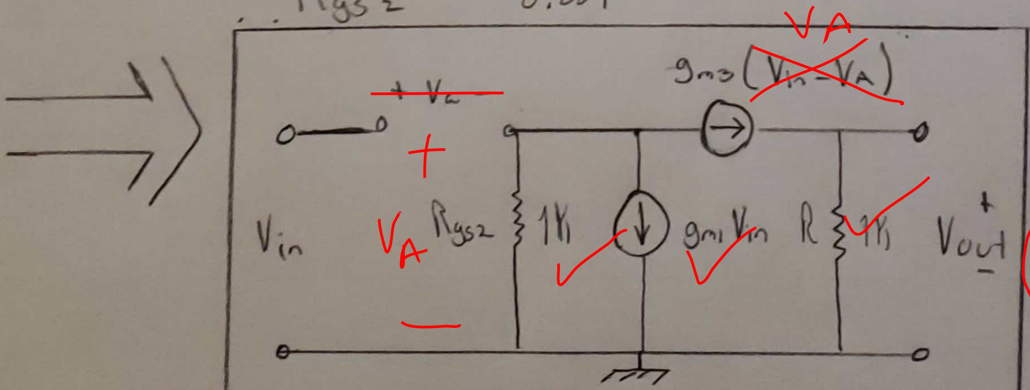


Apply: $R = 1K\Omega$, $g_{m3} = 4mS$, $g_{m2} = 1mS$, $g_{m1} = 10mS$

$V_{gs1} = V_{in}$

$V_{gs3} = (V_{in} - (V_a))$

$\therefore R_{gs2} = \frac{1}{0.001} = 1K\Omega$



where $g_{m3} = 4mS$, $g_{m1} = 10mS$

−3

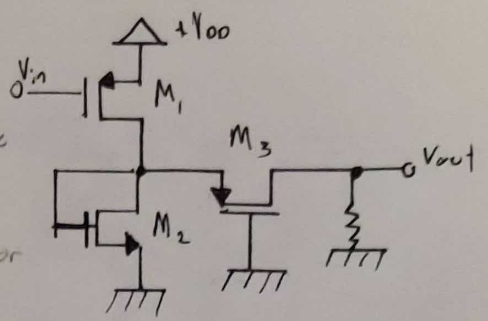
5 Sanity Check:

KVL's remained consistent throughout the full procedure ✓

$\boxed{15/20}$

3(b)

1. **Situation:** For the given amplifier, Use the Same given Values as 3(a.) b.) Find the small signal output resistance expression and its value



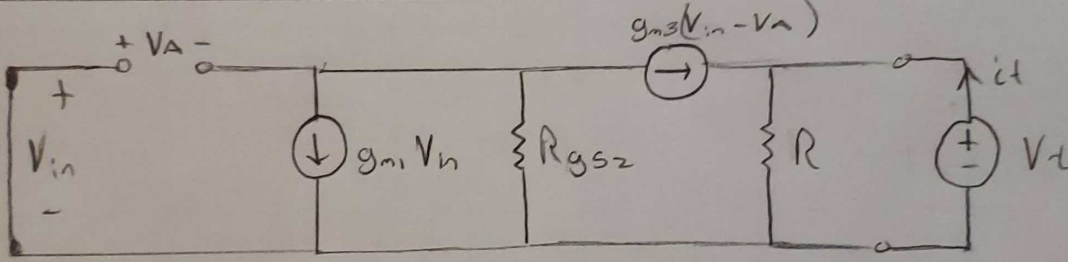
2. **Goal:** To determine an expression for the given amplifier's Rout.

3. **Plan:** To perform Small Signal analysis, following the procedure to solve For Rout, then evaluate. Use SSEC found in 3a

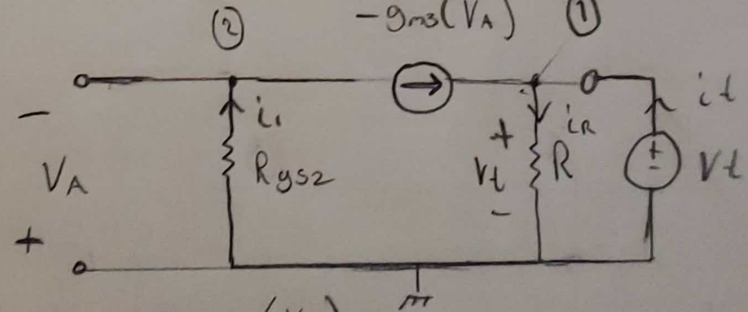
4. **Solution:** Apply Vt to output, Short input, then Solve for

$$R_{out} = V_t / i_t \Big|_{z_{in}=0}$$

Redraw SSEC With Vt and Vin → Short



$\therefore V_{in} = 0$, $g_{m1} V_{in} \rightarrow$ Short



KCL @ 2: $i_1 = -g_{m3}(V_A)$

$$V_A / R_{gs2} = -g_{m3}(V_A)$$

$$\therefore V_A \left(\frac{1}{R_{gs2}} + g_{m3} \right) = 0$$

$$\therefore V_A = 0$$

$\boxed{3(b)}$ (continued)

KCL @ ①: $\quad -g_{m3}V_A + i_t = i_R$

$$i_t = i_R$$

$$\therefore V_t / i_t = R$$

$$\boxed{\therefore R_{out} = R = 1000\,\Omega}$$

Sanity Check:

I'm uncertain that this is correct, but I found no other way to solve Rout.

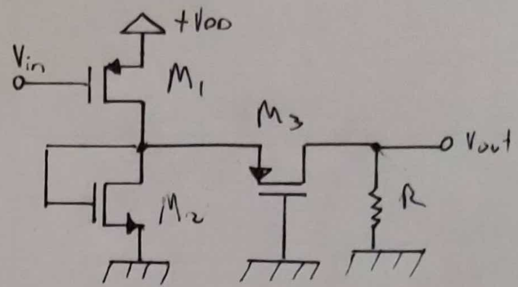
V_A is not shorted, so I'm not sure how it could be zero.

$\boxed{17/20}$

Tristan Denning | Problem 3(c) | HW # 06

3(c)

1 **Situation:** For the given amplifier, Determine the Small Signal transconductance expression and Value G_m.

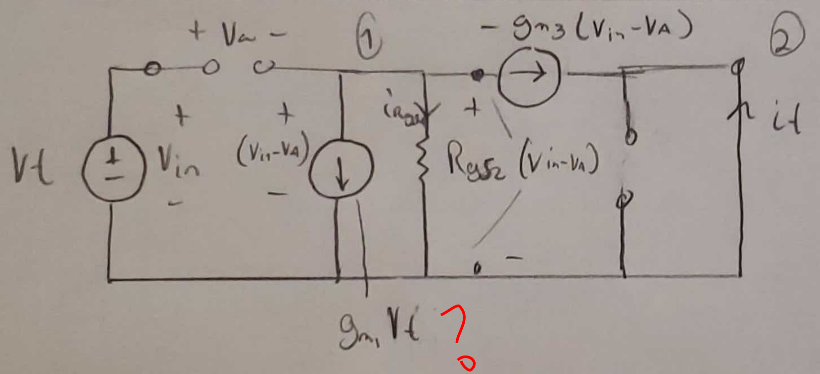


2 **Goal:** To Derive an expression for G_m, then evaluate

3 **Plan:** To perform SS analysis on the SSEC found in 3(a), by Shorting the output, and placing Vtest between input nodes.

4 **Solution:** Solve $G_m = \left.\frac{i_t}{V_t}\right|_{Z_L = 0}$

Redraw with $V_{out} \to$ Short, $V_{in} = V_t$



R ⟹ open circuit

?

KCL @ 1: $-g_{m3}(V_{in}-V_A) = g_{m1}V_t + g_{m2}(V_{in}-V_A)$

$$-(V_{in}-V_A)(g_{m3}+g_{m2}) = g_{m1}V_t$$

$$(V_{in}-V_A) = \frac{-g_{m1}V_t}{(g_{m3}+g_{m2})} \qquad (1)$$

KCL @ 2

$$I_t = g_{m3}(V_{in}-V_A) \qquad (2)$$

(2) → (1)

$$I_t = \frac{-g_{m3}\,g_{m1}\,V_t}{(g_{m3}+g_{m2})}$$

$$\therefore \frac{I_t}{V_t} = \boxed{-\frac{g_{m3}\,g_{m1}}{g_{m3}+g_{m2}} = G_M}$$

3(c) (Continued)

evaluate G_m for $g_{m1} = 10℧$, $g_{m2} = 1℧$,
$g_{m3} = 4℧$

$$\therefore \; G_m = \frac{-4 \cdot 10}{1+4}$$

$$\boxed{G_m = -8 \; mS}$$

s Sanity Check:

Although V_A is not grounded, so $V_A = 0$ may not be the correct assumption, the Unit analysis on G_m checks out.

$$G_m\,[S] = \frac{g_{m3}[S] \cdot g_{m1}[S]}{g_{m3}[S] + g_{m2}[S]}$$

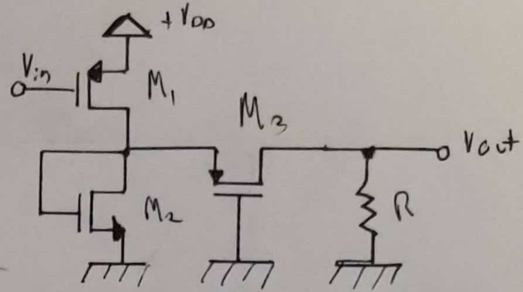
$$= \frac{[S^2]}{S}$$

$$= S \quad \checkmark$$

19/20

$\boxed{3(d)}$

1. **Situation:** For the given amplifier, d.) Find the small signal Voltage gain expression A_v, and evaluate.



2. **Goal:** To determine an expression for A_v, then evaluate.

3. **Plan:** To use the $A_v = R_{out} \cdot G_m$ equation to determine A_v.

4. **Solution:**

$$\text{Eqn: } A_v = R_{out} \cdot G_m$$

$$R_{out} = R$$

$$G_m = \frac{-g_{m3} g_{m1}}{g_{m3} + g_{m2}}$$

$$\therefore \boxed{A_v = \frac{-g_{m3} g_{m1} R}{g_{m3} + g_{m2}}}$$

evaluate:

$$A_v = 1000 \cdot (-8 \times 10^{-3})$$

$$\boxed{A_v = -8}$$

5. **Sanity Check:**

Though my assumption that V_A was 0 may not be correct, the unit analysis is consistent for A_v.

$$A_v [-] = \frac{-\left[\frac{1}{\Omega}\right]\left[\frac{1}{\Omega}\right][\Omega]}{\left[\frac{1}{\Omega}\right]+\left[\frac{1}{\Omega}\right]}$$

$$= \frac{\left[\frac{1}{\Omega}\right]}{\left[\frac{1}{\Omega}\right]}$$

$$= [-] \quad \text{Unitless} \checkmark$$

$\boxed{20/20}$