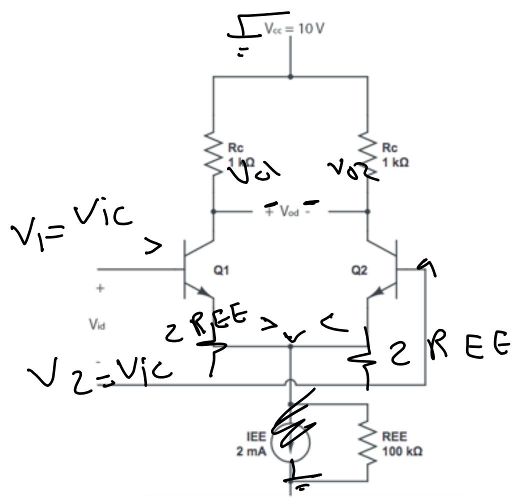
Sheet P.1.1

Sunday, November 6, 2022 9:21 AM

The differential amplifiers shown in the following three figures use two matched BJT's Q_1 and Q_2 with $\beta = 100$ and $V_A = \infty$.

Calculate:

a. The value of collector current for Q_1 and Q_2.
b. The differential mode gain A_{dm}.
c. The common mode gain A_{cm}.
d. The CMRR in decibel (dB).



$I_{E1} = I_{E2} = 1\,mA$

$I_{C2} = I_{C1} = I_{E1}\dfrac{\beta}{1+\beta} = ✓$ $\quad I_b = \dfrac{I_c}{\beta} = ✓$

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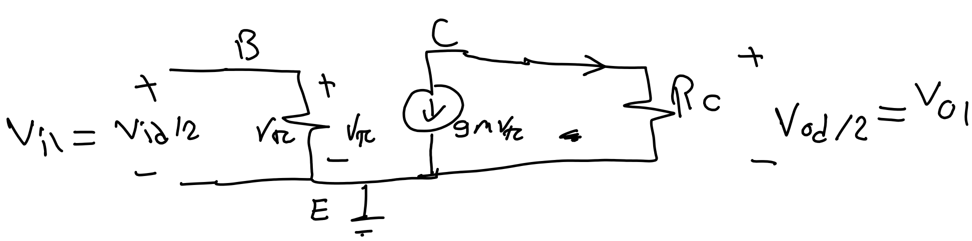
for the left Half of the Circuit



$\dfrac{V_{o1}}{V_{i1}} = ??$

$r_\pi = \dfrac{V_T}{I_b} = \dfrac{26\,mV}{I_b} = ✓$

$g_m = \dfrac{\beta}{r_\pi}$ ✓ $\rightarrow \beta = g_m r_\pi$

$$r_o = \frac{V_A}{I_C} = \infty$$

$$V_{o1} = -g_m V_\pi R_c \rightarrow ①$$

$$V_\pi = V_{i1} \rightarrow ②$$

$$V_{o1} = -g_m V_{i1} R_c$$

$$\frac{V_{o1}}{V_{i1}} = -g_m R_c = \frac{V_{od}/\cancel{2}}{V_{id}/\cancel{2}} = \frac{V_{od}}{V_{id}} = A_{dm}$$

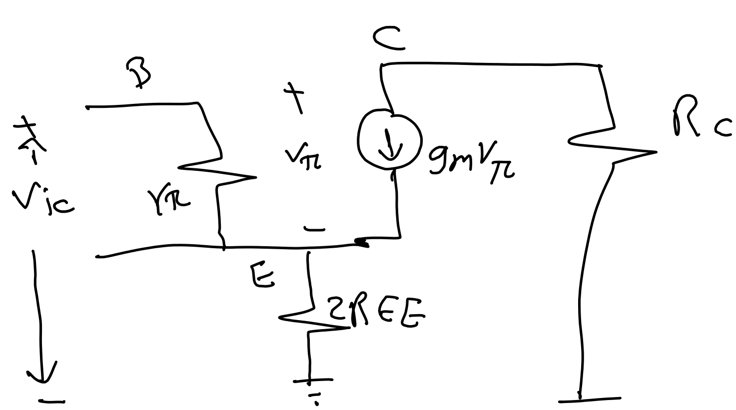
$$V_{od} = V_{o1} - V_{o2}$$

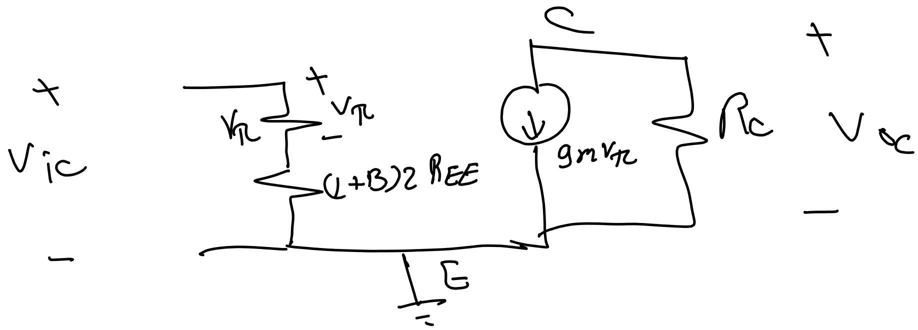
$$= \frac{V_{id}}{2} A - \left(-\frac{V_{id}}{2}\right) A$$

$$= \left(\frac{V_{id}}{2} + \frac{V_{id}}{2}\right) A$$

$$V_{od} = V_{id} A$$

$$A = \frac{V_{od}}{V_{id}}$$





$$V_{oc} = -g_m V_\pi R_C$$

$$V_\pi = V_{ic}\,\frac{r_\pi}{r_\pi + 2R_{EE}(1+\beta)}$$

$$V_{oc} = -g_m R_C\, V_{ic}\,\frac{r_\pi}{r_\pi + 2R_{EE}(1+\beta)}$$

$$\frac{V_{oc}}{V_{ic}} = \frac{-g_m R_C\, r_\pi}{r_\pi + 2R_{EE}(1+\beta)} = A_{cm} = \checkmark = \frac{-R_C}{2R_{EE}}$$

$$= \frac{-\dfrac{\cancel{\beta}\, R_C}{\cancel{\beta}}}{\dfrac{\cancel{r_\pi}}{\cancel{\beta}} + \dfrac{2R_{EE}(\cancel{1+}\beta)}{\cancel{\beta}}}$$

$\because\ 2R_{EE} \gg \frac{r_\pi}{\beta}$

$$A_{cm} = \frac{-R_C}{2R_{EE}\uparrow}$$

$$CMRR\big|_{dB} = 20\log\left(\frac{A_{dm}}{A_{cm}}\right)$$

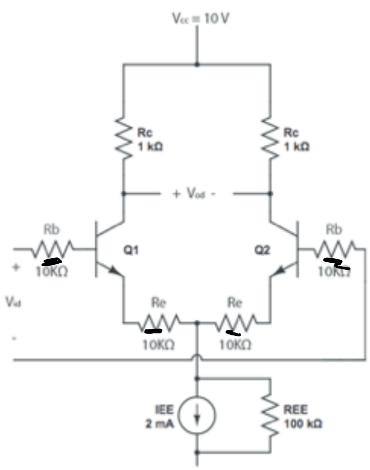
Sheet P.1.2

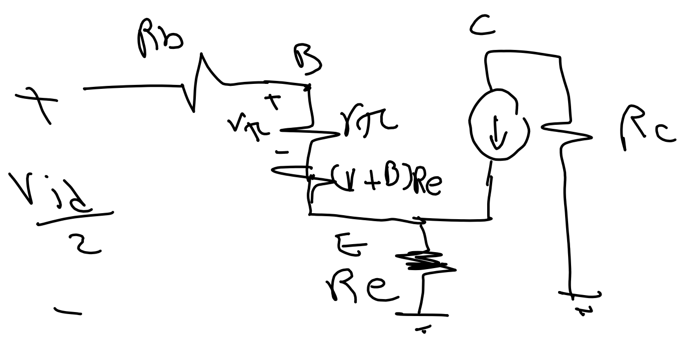
Sunday, November 6, 2022 9:23 AM

The differential amplifiers shown in the following three figures use two matched BJT's Q_1 and Q_2 with $\beta = 100$ and $V_A = \infty$.

Calculate:

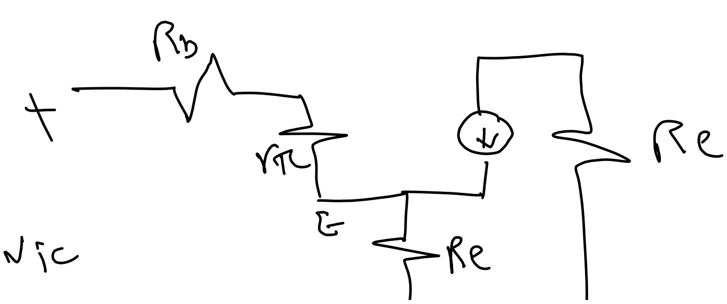
a. The value of collector current for Q_1 and Q_2.
b. The differential mode gain A_{dm}.
c. The common mode gain A_{cm}.
d. The CMRR in decibel (dB).





$$\frac{V_{od}}{2} = -g_m R_C V_\pi$$

$$V_\pi = \frac{V_{id}}{2} \cdot \frac{r_\pi}{r_\pi + R_b + (1+\beta) R_e}$$

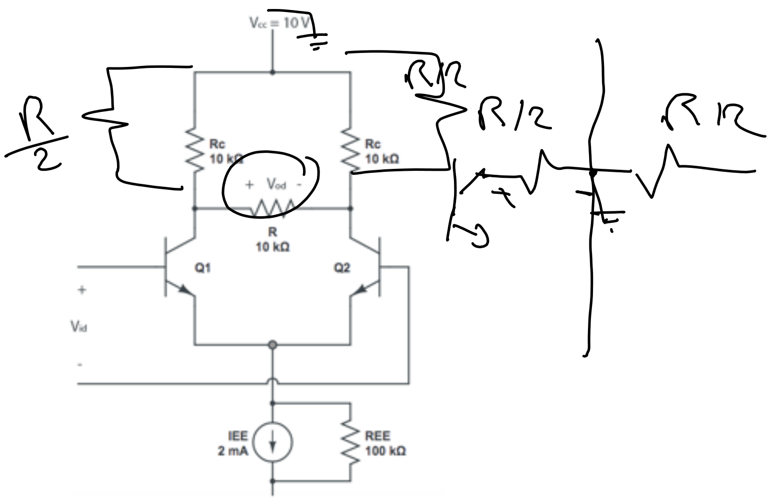


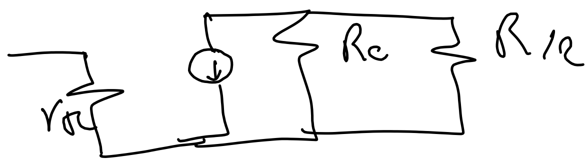
Sheet P.1.3

Sunday, November 6, 2022 9:24 AM

The differential amplifiers shown in the following three figures use two matched BJT's Q_1 and Q_2 with $\beta = 100$ and $V_A = \infty$.
Calculate:

a. The value of collector current for Q_1 and Q_2.
b. The differential mode gain A_{dm}.
c. The common mode gain A_{cm}.
d. The CMRR in decibel (dB).



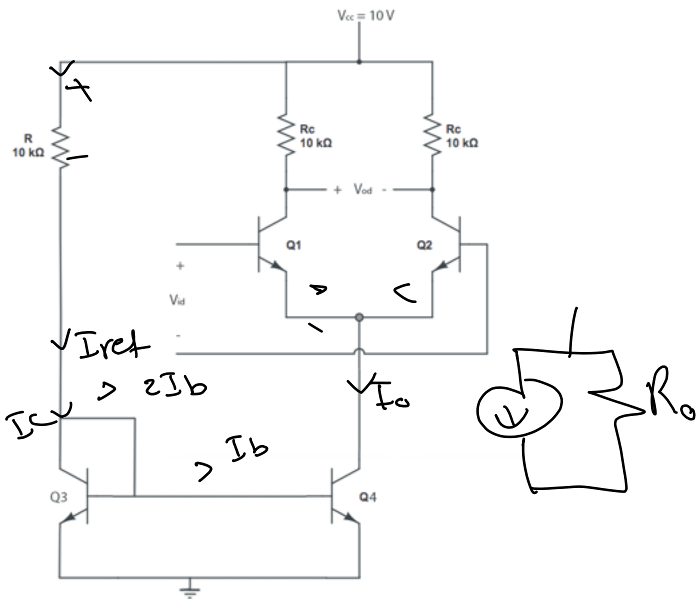


Sheet P.2

Sunday, November 6, 2022 9:26 AM

The differential amplifier shown in the following figure uses the current mirror current source Q_3 and Q_4 with $\beta = 200$ and $V_{A3} = V_{A4} = 120\ V$.
If $V_{A1} = V_{A2} = \infty$, Calculate:

a. The value of collector current for Q_1 and Q_2.
b. The differential mode gain A_{dm}.
c. The common mode gain A_{cm}.
d. The CMRR in decibel (dB).



$$I_{ref} = \frac{10 - 0.7}{R} = \checkmark = 0.93\ mA$$

$$I_o = \cancel{I_{ref} \Rightarrow}$$

$$I_o = I_{ref} \frac{\beta}{\beta + 2} = \checkmark$$

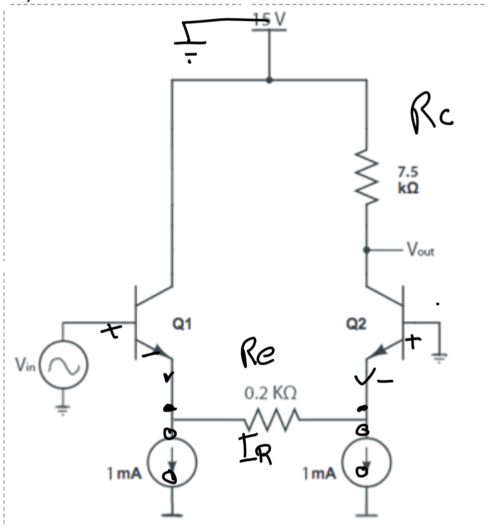
$$I_{E1} = I_{E2} = \frac{I_o}{2}$$

$$R_o = r_o = \frac{V_A}{I_C} \Rightarrow r_{o4} = \frac{120}{I_o} = \checkmark$$

Sheet P.3

Saturday, November 12, 2022 6:56 PM

For the differential amplifier shown in the following figure, calculate the voltage gain, input and output resistances. ($\beta = 100$, $V_{A1} = V_{A2} = \infty$)

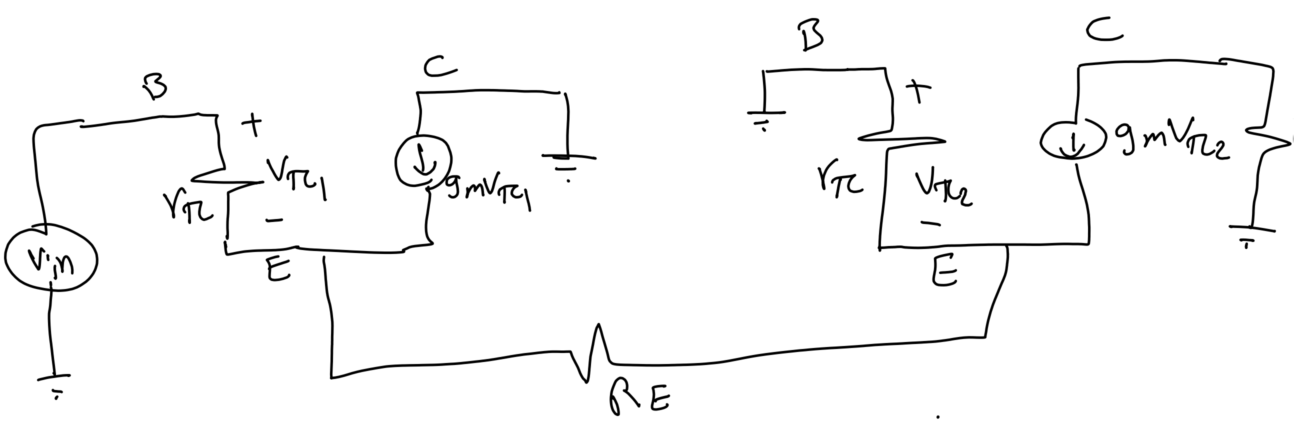


$V_{E1} = -V_{BE1}$ $\qquad V_{E2} = -V_{BE2}$

$$I_R = \frac{V_{E1} - V_{E2}}{R} = 0$$

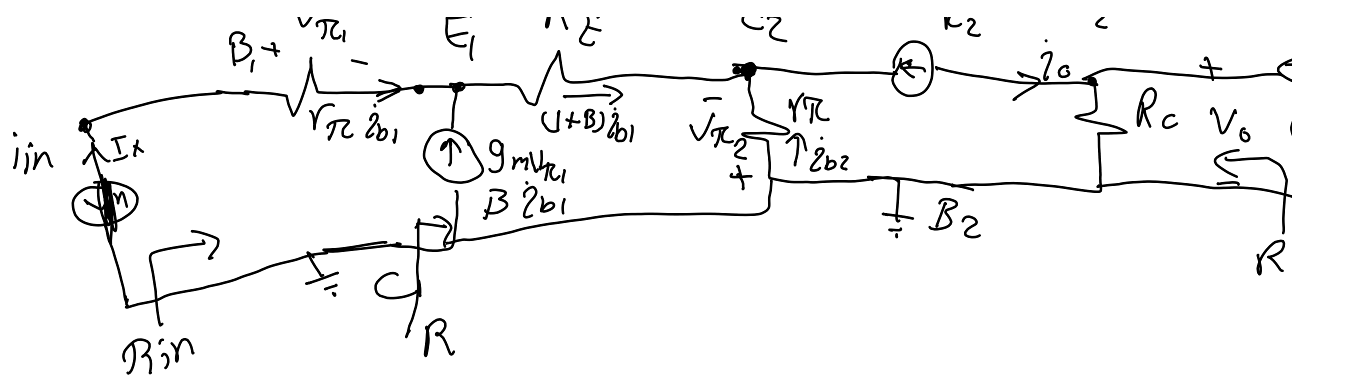
$I_{E1} = I_{E2} = 1\,mA$

$I_C =$ ✓ $\qquad I_B =$ ✓



βi_{b2}

$g_m V_\pi$



$\beta = g_m r_\pi$

Apply KCl at E_2

$$\beta \dot{i}_{b2} + \dot{i}_{b2} + (1+\beta)\dot{i}_{b1} = 0$$

$$\cancel{(1+\beta)}\dot{i}_{b2} = -\cancel{(1+\beta)}\dot{i}_{b1}$$

$$\boxed{\dot{i}_{b2} = -\dot{i}_{b1}}$$

$$V_o = -\beta \dot{i}_{b2} R_C$$

$$V_o = \beta \dot{i}_{b1} R_C \longrightarrow ①$$

$$V_{in} = \dot{i}_{b1} r_\pi + (1+\beta) R_E \dot{i}_{b1} + (-\dot{i}_{b2} r_\pi)$$

$$= \dot{i}_{b1} r_\pi + (1+\beta) R_E \dot{i}_{b1} + \dot{i}_{b1} r_\pi$$

$$V_{in} = \dot{i}_{b1} (2 r_\pi + (1+\beta) R_E)$$

$$\dot{i}_{b1} = \frac{V_{in}}{2 r_\pi + (1+\beta) R_E} \longrightarrow ②$$

from ② ⟶ ①

$$\frac{V_o}{V_{in}} = \frac{\beta R_C}{2r_\pi + (1+\beta) R_E} = \checkmark$$

$I_R = i_{b1}$

$V_R = (1+\beta) i_{b1} R_E + i_{b1} r_\pi$

$$R = \frac{V_R}{I_R} = (1+\beta) R_E + r_\pi$$

$R_{in} = 2r_\pi + (1+\beta) R_E$

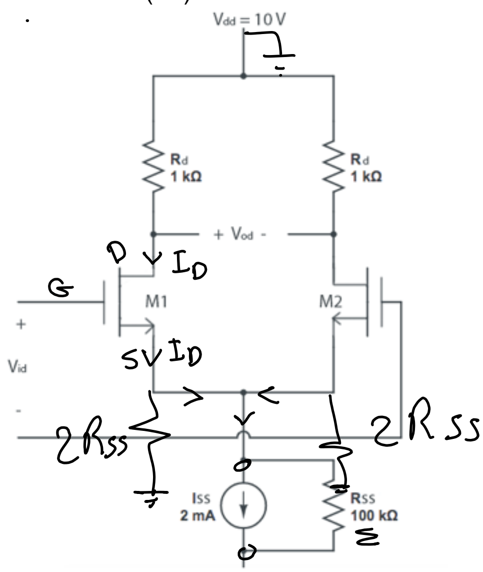
$R_{out} = R_C$

Sheet P.4

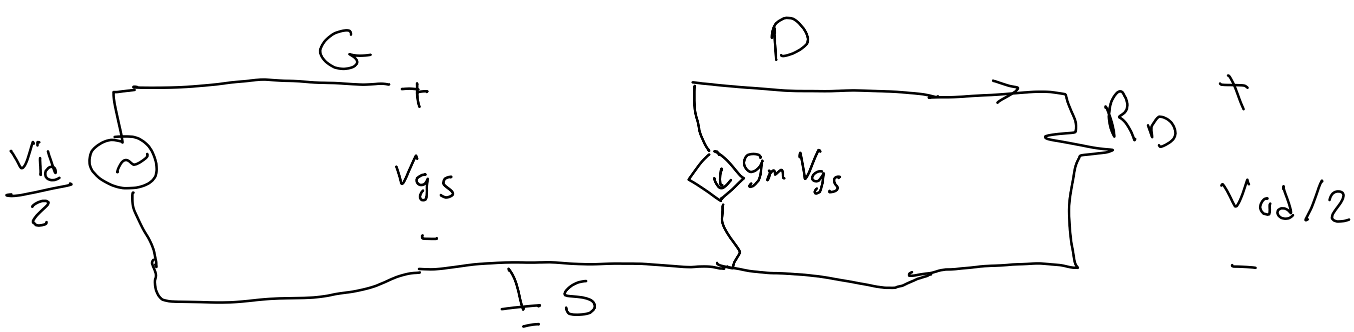
Saturday, November 12, 2022 6:58 PM

The MOS differential amplifier shown in the following figure uses two matched MOSFET's M_1 and M_2 with K = 2 mA/V^2 and $V_A = \infty$.
Calculate:

a. The value of drain current for M_1 and M_2.
b. The differential mode gain A_{dm}.
c. The common mode gain A_{cm}.
d. The CMRR in decibel (dB).



$I_{D_2} = I_{D_1} = 1mA$



$$g_m = \sqrt{2K\ I_D} = \checkmark$$

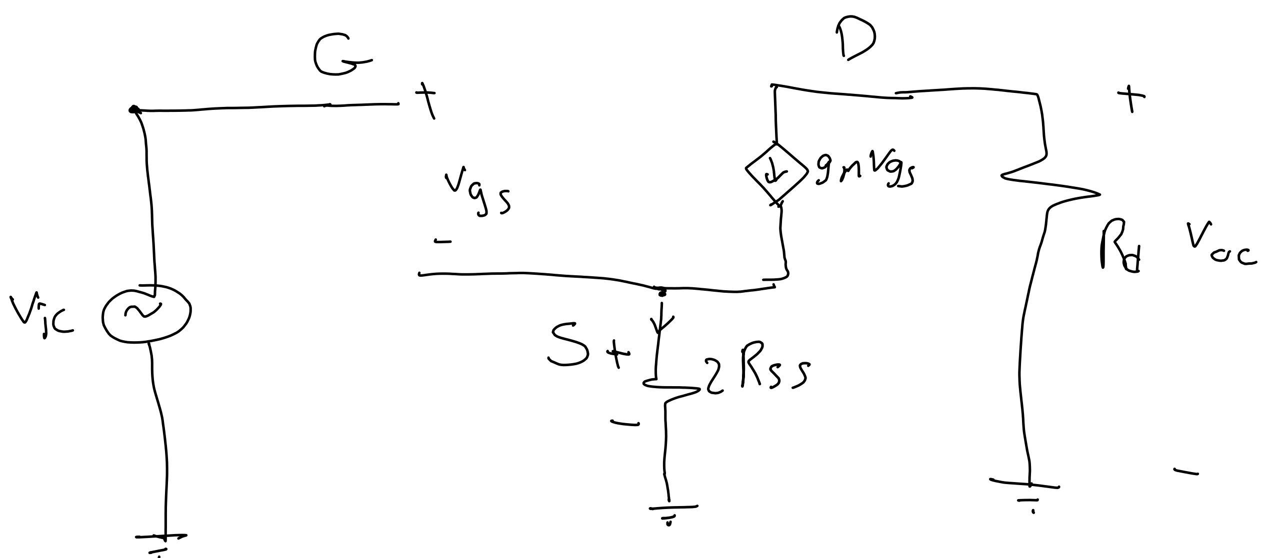
$$r_{ds} = \frac{V_A}{I_D} = \infty$$

$$\frac{V_{od}}{2} = -g_m V_{gs} R_D$$

$$\because V_{id}/2 = V_{gs}$$

$$\therefore \frac{V_{od}}{\cancel{2}} = -g_m R_d \frac{V_{id}}{\cancel{2}}$$

$$\frac{V_{od}}{V_{id}} = -g_m R_D = A_{dm}$$



$$V_{oc} = -g_m V_{gs} R_d$$

$$V_{ic} = V_{gs} + g_m V_{gs} 2R_{ss}$$

$$\frac{V_{oc}}{V_{ic}} = \frac{-g_m \cancel{V_{gs}} R_d}{(1 + g_m 2R_{ss}) \cancel{V_{gs}}} = \frac{-g_m R_d}{1 + 2g_m R_{ss}} = A_{cm}$$

$$CMRR = 20\log\left|\frac{A_{dm}}{A_{cm}}\right| = \checkmark$$

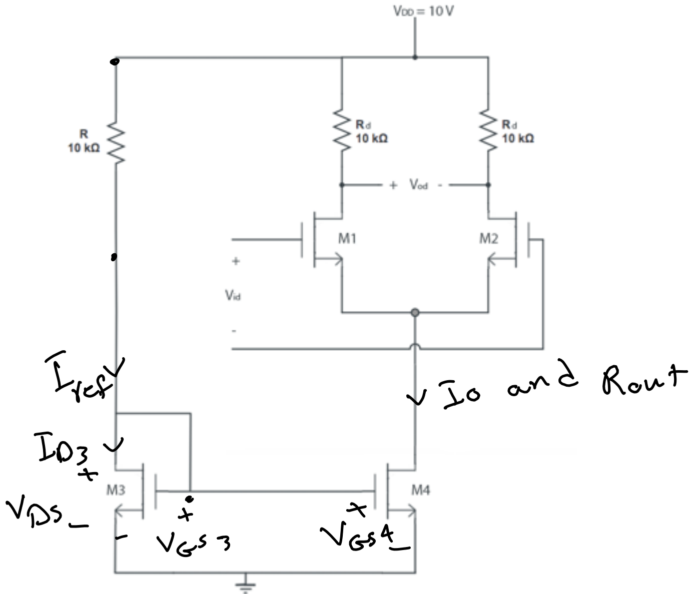
Sheet P.5

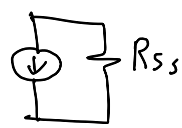
Saturday, November 12, 2022   7:00 PM

The differential amplifier shown in the following figure uses the current mirror current source M_3 and M_4 with K = 0.5 mA/V^2 and $V_{A3} = V_{A4} = 120\ V$.

If $V_{A1} = V_{A2} = \infty$, Calculate:

a. The differential mode gain A_{dm}.
b. The common mode gain A_{cm}.
c. The CMRR in decibel (dB).





$$I_{Ref} = \frac{10 - V_{GS_3}}{10k} = I_{D3} = 1 - 0.1\ V_{GS_3} \longrightarrow ①$$

M_3 is in saturation region

$$V_{DS} > V_{GS} - V_T$$

$\because V_{DS} = V_{GS}$

$\therefore M_3 \rightarrow$ sat.

$$I_{D3} = \frac{K}{2}\left(V_{GS3} - V_T\right)^2 \longrightarrow ②$$

Where $K = K_n = K_n' \cdot \frac{W}{L}$ and $K_n' = \mu_n C_{ox}$

$V_T = 1V$

$$V_{GS3} \rightarrow \begin{cases} 2.71\ V \ \checkmark \\ -1.11\ V \ \times \end{cases}$$

$V_{GS3} = 2.71\ V$

$I_{D3} = 1 - 0.1 * 2.71 = 0.729\ mA$

$\because$ M_3 and M_4 are matched

$\therefore$ $I_{D3} = I_{D4} = I_o = 0.729\ mA$

$$R_{out} = r_{ds4} = \frac{V_{A4}}{I_4} = \frac{120}{0.729} = 164.61\ K\Omega$$

$g_{m1} = g_{m2} = \sqrt{2KI_D} = \checkmark$