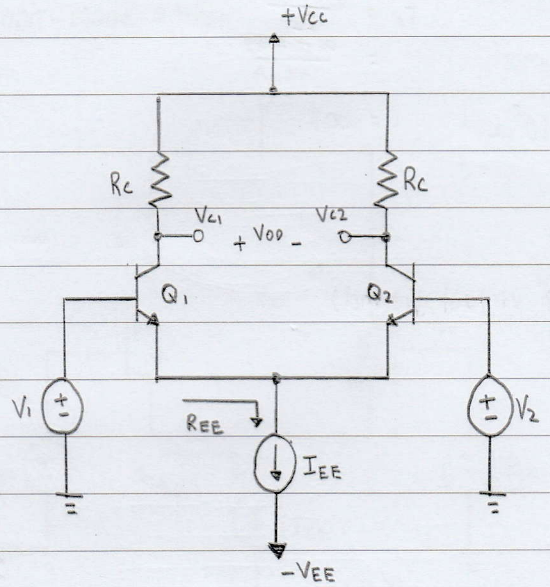
No.: Date:

Esmund Lim A·E Tutorial 8

1)



$V_{CC} = V_{EE} = 12V$

$\beta = 100$

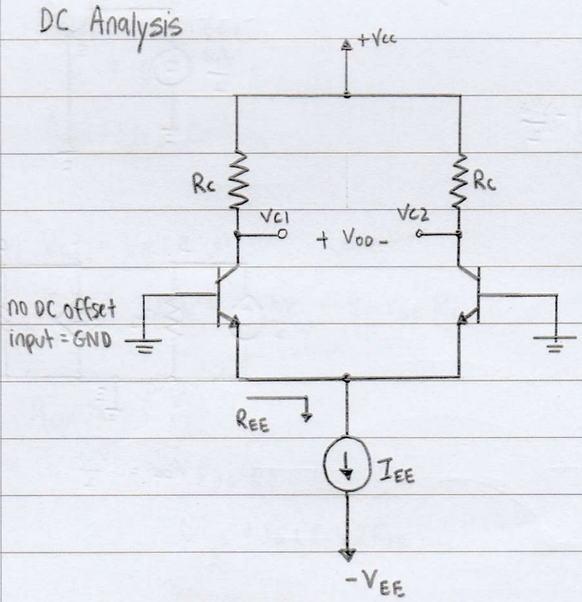
$I_{EE} = 400\mu A$

$R_{EE} = 200k\Omega$

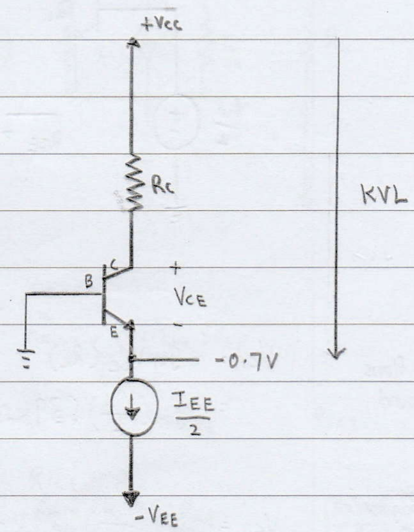
$R_C = 39k\Omega$

$V_A = \infty$

DC Analysis



DC halfcircuit



$$I_C = \alpha I_E$$
$$= \frac{\beta}{\beta+1}\left(\frac{I_{EE}}{2}\right)$$
$$= \frac{100}{100+1}\left(\frac{400\mu A}{2}\right)$$
$$= 198.019802 \times 10^{-6}\ A$$
$$\approx 198\mu A$$

By KVL

$$-V_{CC} + R_C I_C + V_{CE} + (-0.7) = 0$$
$$V_{CE} = V_{CC} - R_C I_C + 0.7$$
$$= 12 - 39k\Omega(198\mu A) + 0.7$$
$$= 4.977227722V$$
$$\approx 4.98V$$

$\therefore$ Q-point

(198μA, 4.98V)

b) $g_m = 40 I_C$

$= 40\,(198\mu A)$

$= 7.92\,mS$

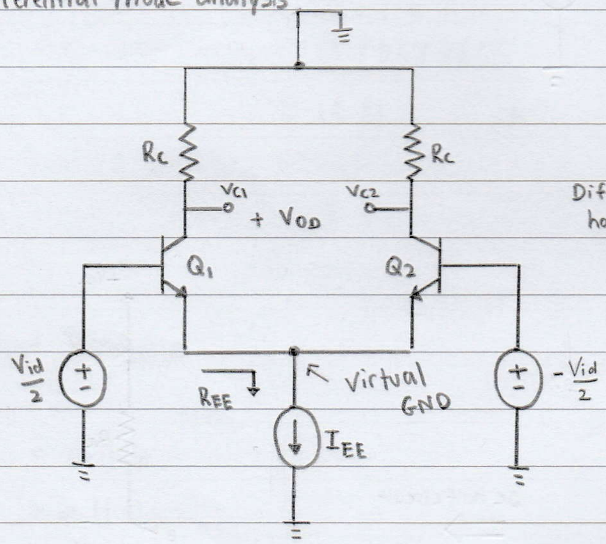
$r_\pi = \frac{\beta}{g_m} = \frac{100}{7.92ms} = 12.62626263 \times 10^3\,\Omega \approx 12.63\,k\Omega$

$r_o = \frac{V_A + V_{CE}}{I_C} = \frac{\infty + 4.98}{198\mu A} = \infty$

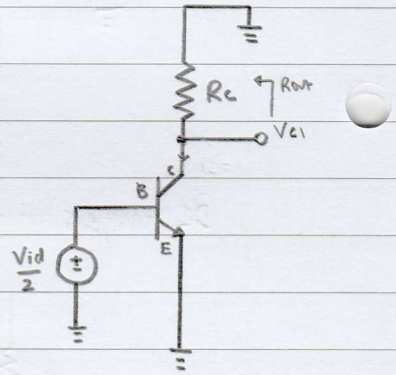
AC Analysis ↗ Differential-mode (with virtual ground)

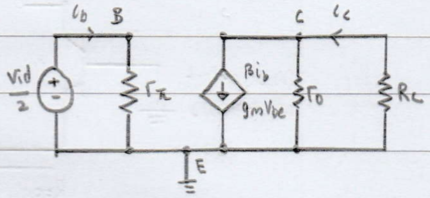
↘ Common-mode

Differential mode analysis



Differential-mode half circuit ⇒





$V_{be} = \frac{V_{id}}{2}$

current flows from ground

$V_{c1} = -g_m V_{be}(R_C)$

$= -g_m\left(\frac{V_{id}}{2}\right)(39k\Omega)$

same magnitude but 180° out of phase as compared to V_{c1}

$V_{c2} = g_m\left(\frac{V_{id}}{2}\right)(39k\Omega)$

basically its 2 of it

$V_{od} = V_{c1} - V_{c2}$

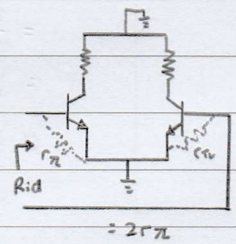
$= -g_m\left(\frac{V_{id}}{2}\right)(39k\Omega) - g_m\left(\frac{V_{id}}{2}\right)(39k\Omega)$

$= -g_m V_{id}\,(39k\Omega)$

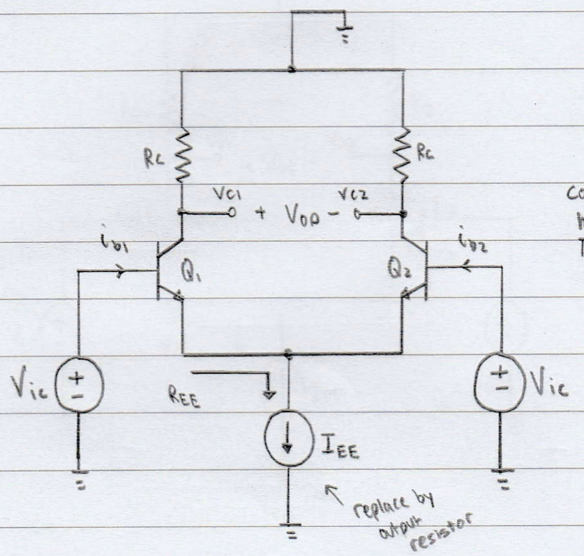
$A_{dm\text{-}diff} = \frac{V_{od}}{V_{id}} = \frac{-g_m \cancel{V_{id}}(39k\Omega)}{\cancel{V_{id}}} = -g_m(39k\Omega) = -7.92mS\,(39k\Omega) = -308.88$

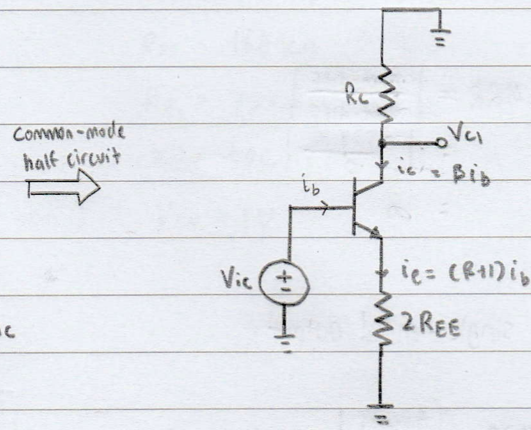
$A_{dm\text{-}se1} = \frac{V_{c1}}{V_{id}} = \frac{-g_m\left(\frac{\cancel{V_{id}}}{2}\right)(R_C)}{\cancel{V_{id}}} = -\frac{g_m R_C}{2} = -\frac{308.88}{2} = -154.44$

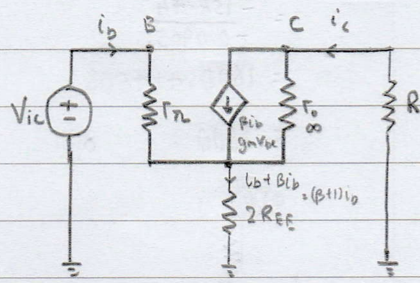
$R_{id} = 2r_\pi = 2\,(12.63k\Omega) = 25.26\,k\Omega$



Common-mode analysis







$V_{od} = V_{c1} - V_{c2}$

$= 0$

$A_{cm\text{-}diff} = 0$

$V_{c1} = V_{c2}$

$= -\beta i_b R_c$ or $-g_m V_{be} R_c$

$$A_{cm\text{-}se1} = \frac{V_{c1}}{V_{ic}}$$

$$= \frac{-\beta \cancel{i_b} R_c}{\cancel{i_b} r_\pi + \cancel{i_b}(\beta+1)2R_{EE}}$$

$$= \frac{-\beta R_c}{r_\pi + (\beta+1)2R_{EE}}$$

$$= \frac{-100\,(39\,k\Omega)}{12.63\,k\Omega + (101 \times 2 \times 200\,k\Omega)}$$

$= -0.09650448387$

≈ -0.0965

$$R_{ic1} = \frac{V_x}{i_x}$$

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

$= r_\pi + (\beta+1)2R_{EE} \quad = R_{ic2}$

$R_{ic} = R_{ic1} \,//\, R_{ic2}$

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

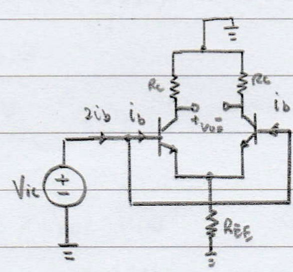
$$\boxed{\frac{A \times A}{2A} = \frac{A}{2}}$$

$$= \frac{12.63\,k\Omega + (101 \times 2 \times 200\,k\Omega)}{2}$$

$= 20.206315 \times 10^6\,\Omega$

$\approx 20.2\,M\Omega$

or



$$R_{ic} = \frac{V_{ic}}{2i_b}$$

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CMRR (Common mode rejection ratio)

For differential output

$$CMRR = \left| \frac{A_{dm-diff}}{A_{cm-diff}} \right|$$
$$= \left| \frac{-308.88}{0} \right|$$
$$= \infty$$

For single-ended output

$$CMRR = \left| \frac{A_{dm-se1}}{A_{cm-se1}} \right|$$
$$= \frac{-154.44}{-0.0965}$$
$$= 1600.414508$$
$$\approx 1600 \quad \text{or} \quad \text{convert to dB}$$
$$= 20 \log 1600$$
$$= 64.08239965$$
$$\approx 64.1 \text{ dB}$$

Output Resistance

$$R_{o1} = R_{o2}$$
$$= r_o \| 39k\Omega$$
$$= 39k\Omega$$

$$R_{od} = R_{o1} + R_{o2}$$
$$= 39k\Omega \times 2$$
$$= 78k\Omega$$

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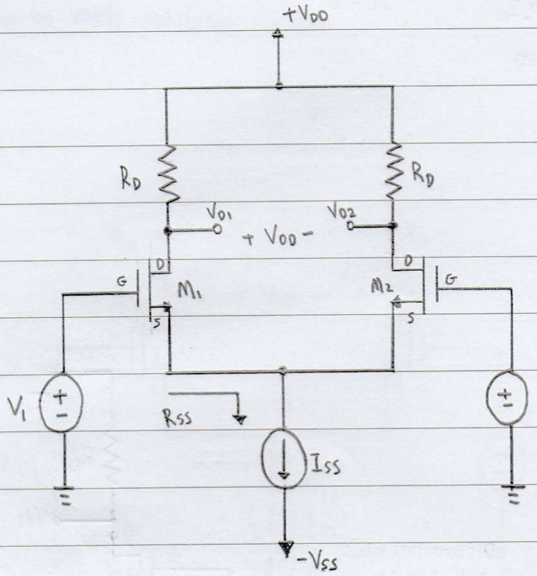
2)



$V_{DD} = V_{SS} = 15V$

$I_{SS} = 300\mu A$

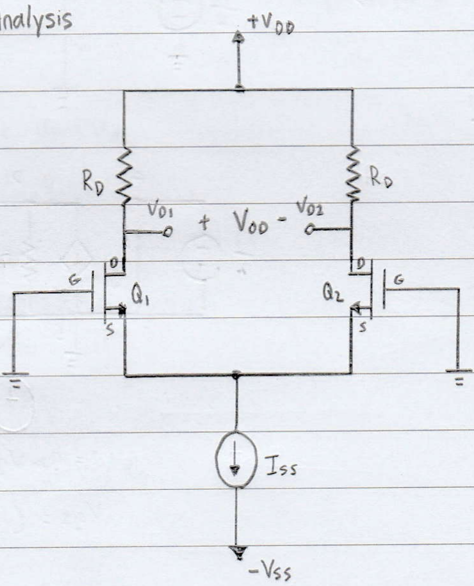
$R_{SS} = 160\,k\Omega$

$R_D = 75k\Omega$

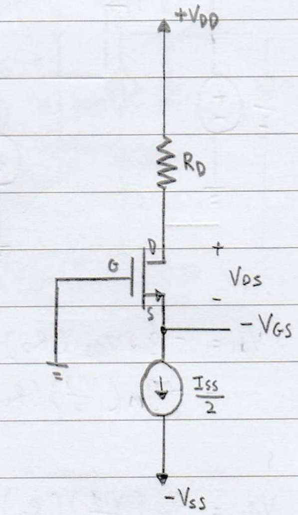
$k_n = 400\mu A / V^2$

$V_{TN} = 1V$

DC Analysis



DC half circuit



Same as source current

$I_D = \frac{I_{SS}}{2}$

$= \frac{300\mu A}{2}$

$= 150\mu A$

$I_D = \frac{k_n}{2}(V_{GS} - V_{TN})^2$

$(V_{GS} - V_{TN})^2 = I_D \div \frac{k_n}{2}$

$V_{GS} - V_{TN} = \sqrt{I_D \times \frac{2}{k_n}}$

$V_{GS} = \sqrt{\frac{2 I_D}{k_n}} + V_{TN}$

$= \sqrt{\frac{2(150\mu A)}{400\mu A}} + 1$

$= 1.866025404\,V$

$\approx 1.866V$

By KVL

$-15 + I_D R_D + V_{DS} + (-1.866) = 0$

$V_{DS} = 15 - I_D R_D + 1.866$

$= 15 - 150\mu A(75k\Omega) + 1.866$

$= 5.616\,V$

$\approx 5.62V$

$\therefore V_{DS} = 5.62V > V_{GS} - V_{TN}$

$= 0.866V$

Q-point

$(150\mu A, 5.62V)$

The MOSFETs are in saturation region

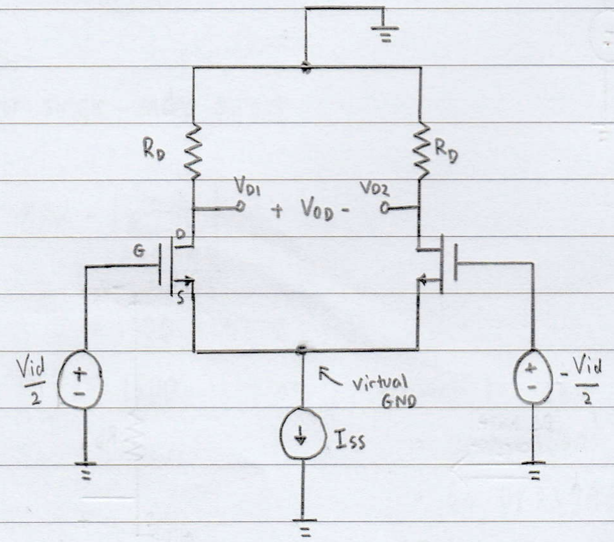
b) $g_m = \sqrt{2 K_n I_D}$ $\qquad r_o = \frac{1}{\lambda I_D}$ $\qquad \lambda = 0$

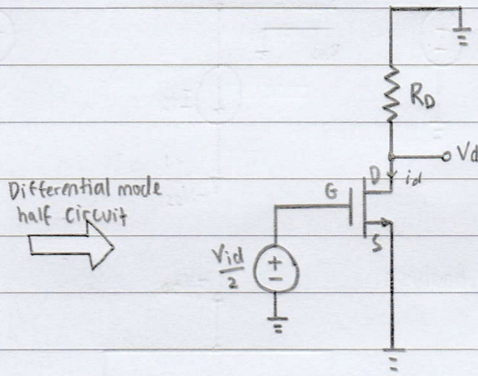
$= \sqrt{2(400\mu A)(150\mu A)}$ $\qquad = \infty$

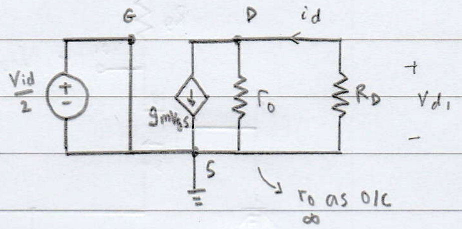
$= 0.346410161 \times 10^{-3}\ S$

$\approx 0.346\ mS$

Differential mode analysis







$V_{d1} = -g_m V_{gs} (R_D)$

$= -g_m \left(\frac{Vid}{2}\right)(R_D)$

$i_d = g_m V_{gs}$

$V_{gs} = \left(\frac{Vid}{2}\right)$

$V_{d2} = g_m \left(\frac{Vid}{2}\right)(R_D)$

$V_{od} = V_{d1} - V_{d2}$

$= -g_m (Vid)(R_D)$

$A_{dm\text{-}diff} = \frac{V_{od}}{Vid}$

$= \frac{-g_m(\cancel{Vid})R_D}{\cancel{Vid}}$

$= -g_m R_D$

$= -(0.346 ms)(75 k\Omega)$

$= -25.95$

$A_{dm\text{-}sel} = \frac{V_{d1}}{Vid}$

$= \frac{-g_m\left(\frac{\cancel{Vid}}{2}\right)(R_D)}{\cancel{Vid}}$

$= \frac{-g_m R_D}{2}$

$= \frac{-25.95}{2}$

$= -12.975$

$R_{id} = \infty$ $\qquad (I_{gate} = 0)$ $\therefore R = \frac{V}{I}$

$= \frac{V}{0}$

$= \infty$

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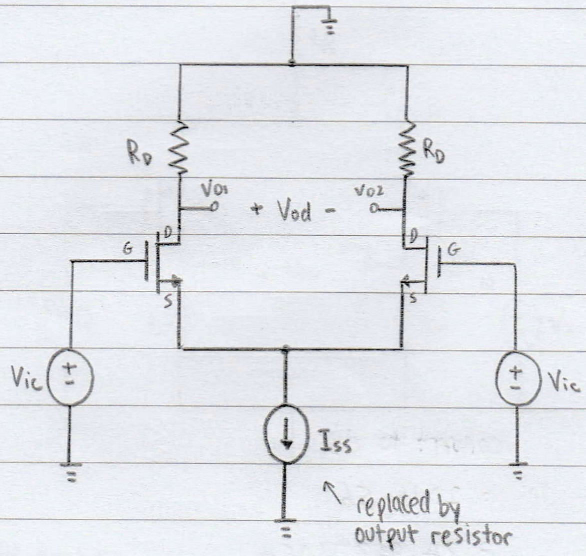
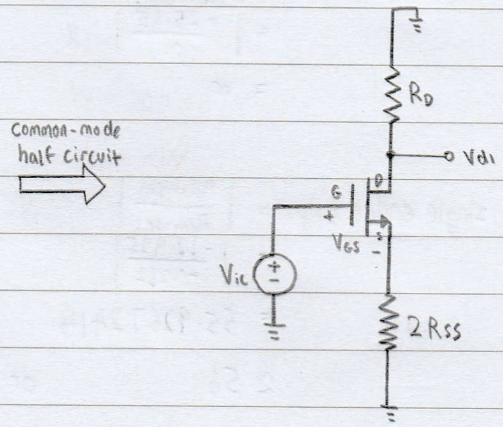
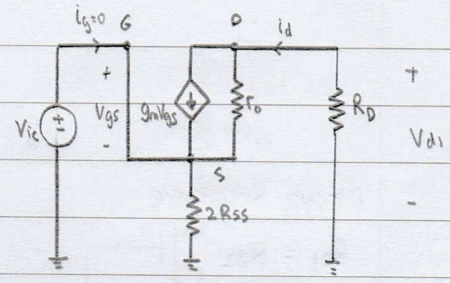
Common mode analysis







$V_{od} = V_{d1} - V_{d2}$

$= 0$

$A_{cm\text{-}diff} = 0$

$V_{d1} = V_{d2}$

$= -g_m V_{gs} R_D$

$$A_{cm-se1} = \frac{V_{d1}}{V_{ic}}$$

$$= \frac{-g_m V_{gs} R_D}{V_{gs} + g_m V_{gs}(2R_{SS})}$$

$$= \frac{-g_m V_{gs} R_D}{V_{gs}(1 + g_m 2R_{SS})}$$

$$= \frac{-0.346mS(75k\Omega)}{(1 + 0.346mS \times 2 \times 160k\Omega)}$$

$$= -0.2322771214$$

$$\simeq -0.232$$

$R_{ic} = \infty$

No.: Date:

CMRR

For differential output $= \left| \frac{A_{dm-diff}}{A_{cm-diff}} \right|$

$= \left| \frac{-25.95}{0} \right|$

$= \infty$

For single ended output $= \left| \frac{A_{dm-se1}}{A_{cm-se1}} \right|$

$= \left| \frac{-12.975}{-0.232} \right|$

$= 55.92672414$

≈ 56 or convert to dB

$= 20 \log 56$

$= 34.96376054$

$\approx 35\ dB$

Output Resistance

$R_{O1} = R_{O2}$

$= r_o \parallel R_D$

$= \infty \parallel 75k\Omega$

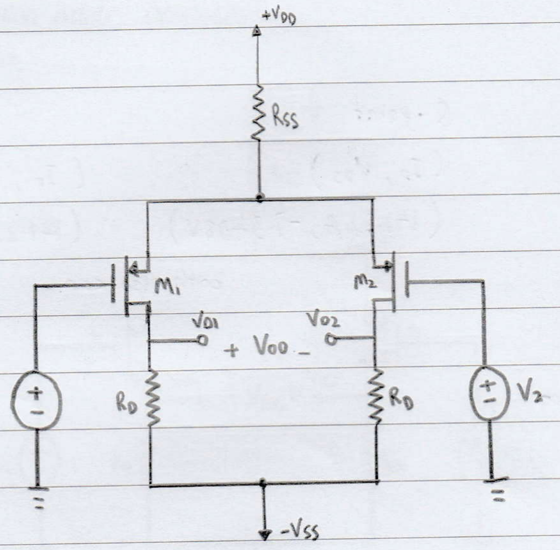
$= 75k\Omega$

$R_{od} = R_{O1} + R_{O2}$

$= 2 \times 75k\Omega$

$= 150k\Omega$

3)



$V_{DD} = V_{SS} = 18V$

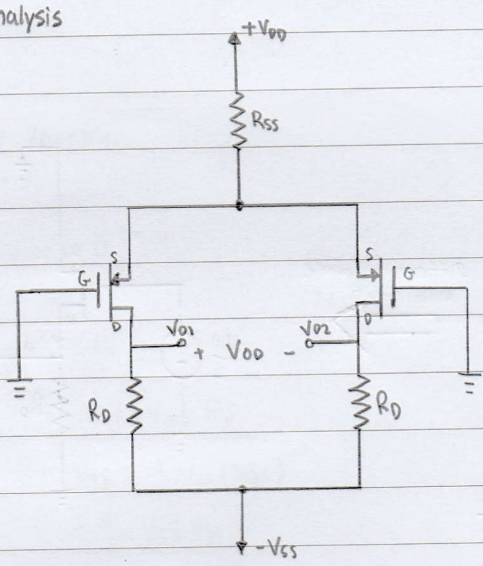
$R_{SS} = 56k\Omega$

$R_D = 91k\Omega$

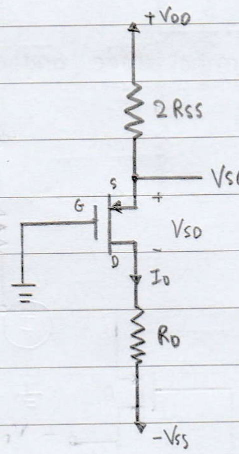
$K_p = 200\mu A/V^2$

$V_{TP} = -1V$

DC analysis



DC half circuit



$$I_D = \frac{V_{DD} - V_{SG}}{2R_{SS}}$$
$$= \frac{18 - V_{SG}}{2(56k\Omega)} \quad \text{— ①}$$

$$I_D = \frac{k_p}{2}(V_{GS} - V_{TP})^2$$
$$= \frac{200\mu A}{2}\left(V_{GS} - (-1)\right)^2 \quad \text{— ②}$$

$$\text{①}: \frac{18 - (-V_{GS})}{2R_{SS}} \quad \text{— ③}$$

$$\text{③} = \text{②}$$
$$\frac{18 + V_{GS}}{2R_{SS}} = \frac{200\mu A}{2}(V_{GS} + 1)^2$$

$$100\mu A\,(V_{GS}+1)^2\,(2R_{SS}) = 18 + V_{GS}$$
$$100\mu A\,(2\times 56k\Omega)(V_{GS}+1)(V_{GS}+1) = 18 + V_{GS}$$
$$11.2\,[V_{GS}^2 + 2V_{GS} + 1] = 18 + V_{GS}$$
$$11.2V_{GS}^2 + 22.4V_{GS} - V_{GS} + 11.2 - 18 = 0$$
$$11.2V_{GS}^2 + 21.4V_{GS} - 6.8 = 0$$
$$V_{GS} = 0.2774648749V$$
$$\approx 0.28V \quad (\text{infeasible})$$
$$\text{or} = -2.1881791161V$$
$$\approx -2.19V$$

$$I_D = \frac{18 - 2.19}{2(56k\Omega)}$$
$$= 141.1607143\times 10^{-6}A$$
$$\approx 141.2\mu A$$

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By KVL

$-V_{SG} + V_{SD} + I_D R_D + (-V_{SS}) = 0$

$V_{SD} = V_{SG} + V_{SS} - I_D R_D$

$= 2.19 + 18 - 141.2\mu A(91k\Omega)$

$= 7.3408V$

Q-point

(I_D, V_{DS})

$(141.2\mu A, -7.3408V)$

(I_D, V_{SD})

$(141.2\mu A, 7.3408V)$

both also can

b) $g_m = \sqrt{2K_pI_D}$

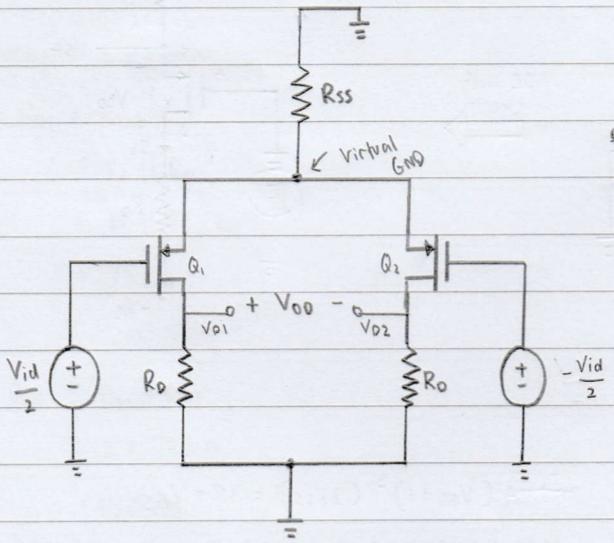
$= \sqrt{2(200\mu A)(141.2\mu A)}$

$= 0.237655212 \times 10^{-3}\, S$

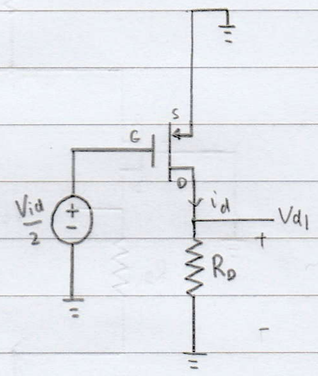
$\approx 0.2376mS$

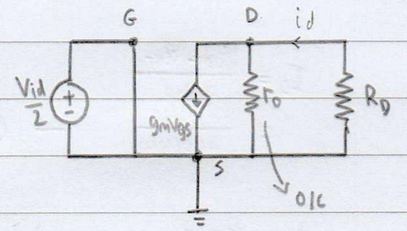
$r_o = \infty$

Differential mode analysis



Differential mode half circuit





$V_{d1} = -g_m V_{gs} R_D$

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

$V_{d2} = g_m\left(\frac{V_{id}}{2}\right)R_D$

$V_{od} = V_{d1} - V_{d2}$

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

$= -\cancel{2}g_m\left(\frac{V_{id}}{\cancel{2}}\right)R_D$

$= -g_m V_{id} R_D$

$A_{dm\text{-}diff} = \frac{V_{od}}{V_{id}}$

$= \frac{-g_m \cancel{V_{id}} R_D}{\cancel{V_{id}}}$

$= -g_m R_D$

$= -0.2376mS \times 91k\Omega$

$= -21.6216$

$V_{gs} = \frac{V_{id}}{2}$

$A_{dm\text{-}se1} = \frac{V_{d1}}{V_{id}}$

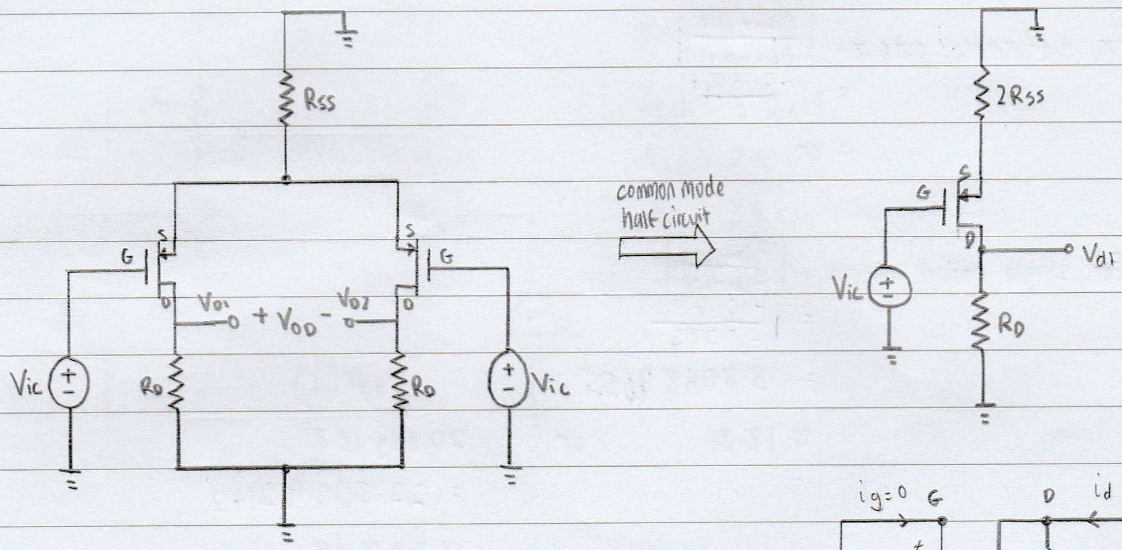
$= \frac{A_{dm\text{-}diff}}{2}$

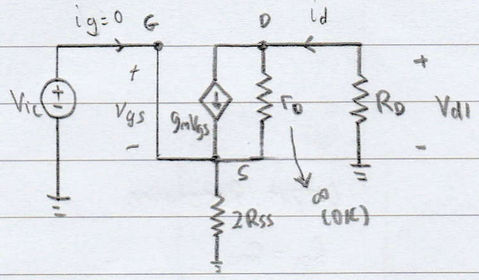
$= \frac{-21.6216}{2}$

$= -10.8108$

$R_{id} = \infty$

common mode analysis





$$V_{od} = V_{d1} - V_{d2}$$
$$= 0$$

$$A_{cm\text{-}diff} = 0$$

$$A_{cm\text{-}sel} = \frac{V_{d1}}{V_{ic}}$$
$$= \frac{-g_m V_{gs} R_D}{V_{gs} + g_m V_{gs}(2R_{ss})}$$
$$= \frac{-g_m \cancel{V_{gs}} R_D}{\cancel{V_{gs}}(1 + g_m(2R_{ss}))}$$
$$= \frac{-g_m R_D}{1 + g_m(2R_{ss})}$$
$$= \frac{-0.2376mS\,(91k\Omega)}{1 + 0.2376mS\,(2 \times 56k\Omega)}$$
$$= -0.7830735354$$
$$\approx -0.783$$

$$R_{ic} = \infty$$

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CMRR

For differential output $= \left| \frac{A_{dm-diff}}{A_{cm-diff}} \right|$

$= \left| \frac{-21.6216}{0} \right|$

$= \infty$

For single ended output $= \left| \frac{A_{dm-se1}}{A_{cm-se1}} \right|$

$= \left| \frac{-10.8108}{-0.783} \right|$

$= 13.80689655$

≈ 13.81 or $20 \log 13.81$

$= 22.80192142$

$\approx 22.8\, dB$

Output Resistance

$R_{o1} = R_{o2}$

$= r_o \parallel R_D$

$= \infty \parallel 91k\Omega$

$= 91k\Omega$

$R_{od} = 2 \times 91k\Omega$

$= 182k\Omega$